Data Product and Archive Volume Software Interface Specifications

EPOXI

Raw and Calibrated Science Data Products for

Hi-Res IR Spectrometer (HRII) Hi-Res Visible CCD (HRIV) Medium-Res Visible CCD (MRI)

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Modification History

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2007-10-11	S. McLaughlin	Created draft
2008-05-21	S. McLaughlin	Updated many sections
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1 Introduction

1.1 Purpose and Scope

The purpose and scope of this document is to describe the Level 2 (raw) and Level 3/4 (calibrated) science data products generated by the Cornell Science Data Center (SDC) pipeline for the three EPOXI instruments as well as the format and content of the PDS archival data sets. The processing levels are defined in Appendix 7.3. This document is intended to provide enough information to enable users to understand and use the data products, and it includes examples of the science data products and information about how the data were processed, formatted, and labeled.

This document is not intended to provide a detailed description of the EPOXI instruments nor does it provide methods for interpreting the scientific data. For a thorough discussion of the EPOXI instruments, see by Hampton, et al. 2005 [4]. The Deep Impact Instrument Calibration paper by Klaasen, et al. 2008 [7] describes an existing calibration pipeline that is the basis for EPOXI. For overviews of the Deep Impact flyby spacecraft and the autonomous navigation system, see A'Hearn, et al. 2005 [5], Blume, 2005 [6], and Mastrodemos, et al. 2005 [8].

1.2 Applicable Documents

1.2.1 External Standard References

[1] PDS Standards Reference, JPL, D-7669, Version 3.7, March 20, 2006.

[2] PDS Data Dictionary, JPL, D-7116, Revision E, August 28, 2002 and the EPOXI Local Data Dictionary created from the PDS Full Data Dictionary generated on January 21, 2009.

1.2.2 Project Documents

The following project-related publications are included in the documentation for the PDS archive. Please note the publishers allowed only ***drafts*** of [4] through [8] to be included in the archive documentation.

[3] EPOXI Data Management and Archiving Plan, JPL, D-39796.

[4] An Overview of the Instrument Suite for the Deep Impact Mission, Hampton et al., Space Science Reviews, 2005, DOI:10.1007/s11214-005-3390-8.

[5] Deep Impact: A Large-Scale Active Experiment on a Cometary Nucleus, A'Hearn, et al., Space Science Reviews, 2005, DOI:10.1007/s11214-005-3387-3.

[6] Deep Impact Mission Design, Blume, Space Science Reviews, 2005, DOI:10.1007/s11214-005-3386-4.

[7] Deep Impact Instrument Calibration, Klaasen, et al., Review of Scientific Instruments, American Institute of Physics, 79, 091301, 2008, DOI: 10.1063/1.2972112, Permalink: http://link.aip.org/link/?RSINAK/79/091301/1.

[8] Autonomous Navigation for the Deep Impact Mission Encounter with Comet Tempel 1, Mastrodemos, et al., Space Science Reviews, 2005, DOI:10.1007/s11214-005-3394-4.

[9] Deep Impact - Navigation Images Report, Project Documentation, Carcich, 2006.

[10] Deep Impact Spacecraft Clock Correlation, Project Documentation, Carcich, 2006.

[11] Deep Impact and EPOXI Instrument Thermal Sensor Atlas, Hampton, 2008.

[12] Deep Impact: The Anticipated Flight Data, Klaasen, et al., Space Science Reviews, 2005.

[13] Restoration of Images of Comet 9P/Tempel 1 Taken with the Deep Impact High Resolution Instrument, Lindler, et al., PASP, 2007.

[14] Deep Impact - Limitations of the HRI-IR Instrument, Groussin and Klaasen, 2006.

[15] EPOXI Data Archive: FITS Keyword Descriptions for the Primary Image Header, Carcich, 2009.

[16] Report on the Calibration of EPOXI spacecraft timing and reduction to Barycentric Julian Date, Hewagama, 2009.

1.2.3 Scientific References

Scientific references, including those from Deep Impact, relevant to EPOXI are listed here.

[A] Deep Impact: Excavating Comet Tempel 1, A'Hearn, et al. 2005, Science, 310, 258-264.

[B] The Extrasolar Planets Encyclopedia, http://exoplanet.eu, J. Schneider, CNRS/LUTH Paris Observatory.

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2 Mission and Instrument Overview

An overview of the EPOXI mission and its three instruments is provided here. The user of the EPOXI data archive is strongly encouraged to read project documents [4] and [7, section II] for thorough discussions of the instruments.

2.1 Mission Overview

The EPOXI mission is the combination of two independently proposed scientific investigations using the flyby spacecraft of Deep Impact in an extended mission. EPOCh (Extrasolar Planet Observation and Characterization) will utilize the HRI CCD and IR spectrometer on the DI flyby spacecraft to a) observe transits by known extrasolar planets (hot Jupiters) to look for perturbations due to terrestrial planets in low-order resonances, b) search those same systems for secondary occultations of the hot Jupiter by the star, and c) characterize the Earth as a remotely sensed planet. DIXI (Deep Impact eXtended Investigation) consists of a flyby of 103P/Hartley 2 in order to study a second short-period comet with the same set of instrumentation as was used at 9P/Tempel 1. The original target was 85P/Boethin. When the comet could not definitively be recovered after extensive observations during 2007, the mission selected the backup, 103P/Hartley 2, as the new target.

Table 1 presents a high-level timeline for the mission. It includes revisions for the change of target for DIXI and the extension of EPOCh observations through August 2008 to recover from the suspension of imaging for all of April 2008 due to an anomaly with the downlink signal as well as additional EPOCh observations of Earth at high northern and southern latitudes in 2009 and one EPOCh observation of Mars planned for late 2009.

Phase	Start Date	End Date	Targets
CRUISE	01 Sep 2007	21 Jan 2008	
Earth Flyby	31 Dec 2007	31 Dec 2007	Moon and calibration sources
In-flight Calibrations	04 Oct 2007	21 Jan 2008	Calibration sources
EPOCh	22 Jan 2008	31 Aug 2008	
Exoplanet Transit Obs	22 Jan 2008	31 Aug 2008	HAT-P-4, XO-3, TrES-3, XO-2, GJ 436, TrES-2, WASP-3, and HAT-P-7
Earth Obs #1	18 Mar 2008	19 Mar 2008	Earth (as a remotely-sensed planet)
Earth Obs #2 and 3	Apr/May 2008	Apr/May 2008	Cancelled due to telecom anomaly
Earth Obs #4	28 May 2008	29 May 2008	Earth (as a remotely-sensed planet)
Earth Obs #5	04 Jun 2008	05 Jun 2008	Earth (as a remotely-sensed planet)
In-flight Calibrations	22 Jan 2008	31 Aug 2008	Calibration sources
CRUISE	01 Sep 2008	03 Sep 2010	
EPOCh Earth North	27 Mar 2009	28 Mar 2009	High northern latitudes
EPOCh Earth South	27 Sep 2009	27 Sep 2009	Planned, High southern latitudes
EPOCh Mars Obs	23 Oct 2009	24 Oct 2009	Planned
Earth Flybys	Dec 2008/9	Dec 2008/9	Moon and calibration sources
In-flight Calibrations	01 Sep 2008	03 Sep 2010	Calibration sources
DIXI	04 Sep 2010	16 Dec 2010	
Hartley 2 Approach	04 Sep 2010	03 Nov 2010	103/P Hartley 2
Hartley 2 Encounter	04 Nov 2010	04 Nov 2010	103/P Hartley 2
Lookback Imaging	04 Nov 2010	25 Nov 2010	103/P Hartley 2
In-flight Calibrations	04 Sep 2010	16 Dec 2010	Calibration sources

Table 2 - Visible CCD (HRIV and MRI) Imaging Modes

2.2 IR Spectrometer (HRII)

The High Resolution Imager (HRI) consists of a long-focal-length telescope followed by a dichroic beam splitter that reflects (0.3 to 1.0 microns) light through a filter wheel to a CCD for direct, optical imaging. The beam splitter transmits the near infrared (1 to 5 microns) to a 2-prism spectrometer. For convenience, we consider these as two separate instruments, HRIV (High Resolution Visible CCD) and HRII (High Resolution IR spectrometer), sharing the telescope since the two focal planes operate in parallel asynchronously. The HRI telescope is a classical Cassegrain design with the following parameters:

Primary aperture:	30.0 cm diameter, round
Primary focal ratio:	4.5
Secondary Obscuration:	9.7 cm diameter, round
Secondary magnification:	7.8x (net Cassegrain focal length 1050 cm)
Back focal distance:	30.0 cm

The dichroic beam-splitter has equal transmission and reflection occurring at about 1.05 microns and is placed in front of the telescope focal plane. The spectrometer is a 2-prism design, one of calcium fluoride (CaF_2) and one of zinc selenide (ZnSe) to maximize etendue and minimize problems with order separation. The camera and collimator lead to a net demagnification of 3x, for an effective focal ratio of f/12 and effective focal length of 360 cm in the final beam. The entrance slit subtends on the sky 2.53 milliradians by 10 microradians (0.145 degrees by 2 arcseconds), filling the 512-pixel height of the IR array. The slit width matches the binned pixel (2x2) mode used for most observations.

The near-infrared detector is a 1024 (wavelength) x 512 (spatial) pixel mercury cadmium telluride (HgCdTe) device manufactured by Rockwell using the multiplexer originally developed under contract from the University of Hawaii for use in the WFC3 on HST. Physically, it is a 1024 x 1024 device, but only half of the device is active. Pixels are 18 microns square and normal operations include 2x2 binning (post-readout). Spectral resolving power, because of the 2-prism design, varies from greater than 740 at 1.04 microns down to 210 at 2.6 microns, and back up to 385 at 4.8 microns. Due to saturation problems in warm areas of a cometary nucleus, the central quarter of the detector is covered with a neutral density filter.

When operated in the 512 x 256 pixel, 2x2 binning mode, the HRII instrument has the following field-of-view characteristics:

Spatial

Physical Pixel Size :	36 micrometers
Effective Pixel FOV :	10.0 microradians or 2.06265 arcseconds
Effective FOV :	2.5 milliradians or 0.15 degrees

Spectral

Effective Pixel FOV :	10.0 microradians
Effective FOV :	10.0 microradians (slitwidth)

Note: For unbinned modes, the effective spatial FOV is 5.0 microradians per pixel.

The spectrometer includes an internal stimulator lamp for calibrating between the two quadrants of the spectrometer (i.e., not as a standard calibrator). However the lamp was broken during one of the ground thermal-vacuum tests and was not replaced. Therefore this lamp was never used during the Deep Impact and EPOXI missions.

It is important to note that the readout order of the IR detector affects the timing of the spectra. When a HRII spectral image is displayed using the true-sky convention, the wavelength increases horizontally to the right and the spatial or along-slit direction is vertical. In this orientation, the IR detector was read out from the left and right edges and toward the center and starting with the first row at the bottom and ending with the last row at the top of the display. Since the detector is reset and read out on a pixel-by-pixel basis, the read out order affects the time at which each pixel is exposed, although each pixel has the same exposure duration. Additionally, the end of the spectrometer slit that always points roughly towards the sun is the first line to be readout and the last line to be read out is furthest from the sun, assuming the spacecraft is in its usual orientation with the solar panels pointing roughly toward the sun. For more information about the timing of the spectra, see the IR focal plane and quadrant nomenclature sections of the Deep Impact instrument calibration document by Klaasen, et al. (2008) [7] and the image orientation section below.

The three instruments on the flyby spacecraft, HRII, HRIV, and MRI (Medium Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned as described by Klaasen, et al. (2008) [7].

For a detailed discussion of the instrument and how it was used during the Deep Impact mission, see Hampton, et al. (2005) [4] and Klaasen, et al. (2005) [12]. For the EPOXI mission, the HRII instrument is used for imaging 1) Earth as a remotely-sensed planet, and 2) the encounter with comet 103P/Hartley 2.

Instrument Calibration

The HRII instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during thermal-vacuum tests (TV1, TV2, and TV4) performed in 2002 and 2003. In-flight calibrations continue through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline.

Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. (2008) [7].

Flight Performance

The HRII instrument generally performed as expected during flight. During Deep Impact, small changes in instrumental temperatures affected the dark current more than expected from ground thermal-vacuum tests. This effect continues for EPOXI and is discussed in the Deep Impact instrument calibration paper by Klaasen, et al. (2008) [7]. Also for the prime mission in 2005, about 1.15% of the IR pixels were bad. Calibration data acquired three years later in 2008 for EPOXI show the fraction of bad pixels has increased to about 1.48%. Therefore new bad pixel maps were generated and incorporated into the calibration pipeline for EPOXI processing.

During the Deep Impact mission, early images of stars acquired by the HRIV CCD indicated the HRI telescope was out of focus. An analysis showed the focus was forward of the HRIV CCD, so bakeouts were performed in late February and early March 2005 to improve the focus. The bakeouts reduced the defocus from 1.0 cm to 0.6 cm, which caused the width of star images to decrease from about 12 pixels to about 9 pixels in a HRIV frame. This focus problem had only a nominal effect on the HRII instrument. For a detailed discussion about the focus of the HRI telescope, please see Klaasen, et al. (2008) [7].

EPOXI Observations

Sections 3.2.1, 3.2.2, and 3.2.3 describe the HRII observations for EPOXI.

2.2.1 Spectrometer Imaging Modes

The imaging modes for the HRII instrument are provided in Table 1.

#	Mode Mnemonic	Mode	Stored Image Size (x, y)	Minimum Exposure Time (sec)	Frame to Frame Time for Minimum Exposure (sec)
1	BINFF	Binned Full Frame	512 x 256	2.86	2.862
2	BINSF1	Binned Sub-Frame 1	512 x 128	1.43	1.432
3	BINSF2	Binned Sub-Frame 2	512 x 64	0.71	0.717
4	UBFF	Un-binned Full Frame	1024 x 512	2.86	2.862
5	ALTFF	Alternating Binned Full Frame	512 x 256	1.43	2.868
6	DIAG	Diagnostic: One reset frame followed by a separate read frame	1024 x 512 (each frame)	1.43 (each frame)	1.432 (each frame)
7	MEMCK	Memory Check	1024 x 512	N/A	2.862

Table 1 - IR Spectrometer (HRII) Imaging Modes

For diagnostic mode 6, a reset frame is acquired first, then a read (i.e., data) frame. Each frame is stored as a separate file. Both data files use the same exposure ID with consecutive image numbers (e.g., exposure ID 1021000 and image number 001 for the reset frame and 002 for the read frame).

The IR detector has several reference columns (line samples) and rows (lines) around the edge of the array. **Pixels in the reference areas are excluded from the MINIMUM and MAXIMUM values in the PDS labels.** See Hampton, et al. 2005 [4] for more details about the instrument modes and the number of reference rows and columns for each instrument mode.

2.3 High- and Medium-Resolution Visible CCDs

2.3.1 HRI Visible CCD (HRIV)

The High Resolution Imager (HRI) consists of a long-focal-length telescope with a dichroic beam splitter located in front of the focal plane that reflected visible light (0.3 to 1.0 microns) through a filter wheel to a CCD for direct, optical imaging. The beam splitter transmits the near-infrared light (1 to 5 microns) to a 2-prism spectrometer. For convenience, we consider these as two separate instruments, HRIV (High Resolution Visible CCD) and HRII (High Resolution IR spectrometer), sharing the telescope since the two focal planes operate in parallel asynchronously. The HRI telescope is a classical Cassegrain design with the following parameters:

Primary aperture:	30.0 cm diameter, round
Primary focal ratio:	4.5
Secondary Obscuration:	9.7 cm diameter, round
Secondary magnification:	7.8x (net Cassegrain focal length 10.5 m)
Back focal distance:	30.0 cm

The dichroic beam-splitter has equal transmission and reflection occurring at about 1.05 microns. The filter wheel contains two clear apertures and 7 filters. Five of the filters are roughly 100 nanometers in bandwidth, centered at 450, 550, 650, 750, and 850 nanometers. The shortest-wavelength filter is effectively a short-wavelength pass filter starting at 400 nanometers and limited to about 340 nanometers on the short end by the rapid decline in beamsplitter reflectivity. The longest wavelength filter is a long-pass filter starting at 900 nanometers that uses the CCD response to define the long-wavelength cutoff at about 960 nanometers.

The visible detector is a 1024 x 1024 split-frame, frame-transfer CCD with 21-micron-square pixels, with each quadrant read out through a separate amplifier. The electronics allow readout of centered sub-frames in multiples of 2: 64x64, 128x128, and so on, with or without rows of overscan. Transfer time, to move the two halves of the image from the exposing area to the two, shielded areas, is about 5.2 milliseconds. Readout time for a full frame is about 1.8 seconds.

The HRIV instrument in full-frame 1024 x 1024 mode has the following field-of-view characteristics:

Pixel Size:	21 micrometers
Pixel FOV:	2.0 microradians or 0.41253 arcseconds
Instrument FOV:	2.0 milliradians or 0.118 degrees
Surface Scale:	1.4 meters/pixel at 700 kilometers

The HRIV instrument includes an internal stimulator lamp for calibrating between the four quadrants of the CCD. The lamp is not a standard calibrator. One of its in-flight uses is to improve the photometry from the EPOXI exoplanet transit observations.

The three instruments on the flyby spacecraft, HRII, HRIV, and MRI (Medium Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned as described by Klaasen, et al. (2008) [7].

For navigation imaging [9], an HRIV observation is typically snipped into one, or more, smaller rectangular areas containing the target(s) of interest to reduce the download time. This processing is performed onboard the spacecraft, and the snips for each observation are downloaded as individual packets. The Deep Impact Science Data Center at Cornell University reconstructs the packets for each observation into the original, raw, 1008x1008 pixel image, without overclock rows and columns [7].

For a detailed discussion of the instrument and how it was used during the Deep Impact mission, see Hampton, et al. (2005) [4] and Klaasen, et al. (2005) [12]. For the EPOXI mission, the HRIV instrument is used for imaging 1) transits of known extrasolar planets, 2) Earth as a remotely-sensed planet, and 3) the encounter with comet 103P/Hartley 2.

Instrument Calibration

The HRIV instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during thermal-vacuum tests (TV2 and TV4) performed in 2002 and 2003. In-flight calibrations continue through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. (2008) [7].

Calibration analysis combining Deep Impact and early EPOXI data determined the two halves of the HRIV CCD - the boundary being the two horizontal central lines 511 and 512 (zero based) - while physically consistent across the boundary, are biased during integration so that the centers of the two halves are apparently 1/6 pixel closer to the center, and the two boundary rows show a decrease in sensitivity of 1/6. Reconstructed image files space all lines evenly, so the true image is erroneously vertically pushed apart by 1/3 pixel at its center in these reconstructions. When making science measurements from HRIV images, one must therefore be very careful to properly account for the two flaws introduced by the apparently narrow central lines on the CCD - a geometric error that separates the image by an extra 1/3 pixel at the horizontal quadrant boundary, and 2) insertion of extra total radiance into calibrated images due to the flat-field correction, which corrects for an apparent radiance deficit in the two central rows because of the smaller number of photons actually incident on those rows.

Flight Performance

The HRIV instrument generally performed as expected during flight. However, images of stars acquired early in the Deep Impact mission indicated the HRI telescope was out of focus. An analysis showed the focus was forward of the CCD, so bakeouts were performed in late February and early March 2005 to improve the focus. The bakeouts reduced the defocus from 1.0 cm to 0.6 cm, which caused the width of star images to decrease from about 12 pixels to about 9 pixels. Star images continued to have a three-fold symmetry (six points) resulting from the three-point mounting of the primary and secondary mirrors. Most of the expected resolution can be regained by applying algorithms to deconvolve the HRIV images as described by Lindler, et al. (2007) [13]. The EPOXI mission takes advantage of the poor focus characteristic which increases the point spread function of measurements, enabling high-precision photometry of known extrasolar planetary systems. For a detailed discussion about the focus of the HRI telescope, see Klaasen, et al. (2008) [7] and Lindler, et al. (2007) [13].

Calibration data acquired in 2008 for EPOXI show a 6% increase in the response of the HRIV 950-nm filter (#5) and changes to the electronic crosstalk between the CCD quadrants since 2005. Therefore new calibration constants for the 950-nm filter and new crosstalk coefficients were calculated and incorporated into the calibration pipeline for EPOXI processing.

EPOXI Observations

Sections 3.2.1, 3.2.2, and 3.2.3 describe the HRIV observations for EPOXI.

2.3.2 MRI Visible CCD (MRI)

The Medium Resolution Imager consists of an f/17.5 Cassegrain telescope followed by a filter wheel feeding directly onto a CCD for direct, optical imaging. The MRI telescope is a classical Cassegrain design with the following parameters:

Primary aperture:	12.0 cm diameter, round
Primary focal ratio:	3.75
Secondary Obscuration:	6.6 cm diameter, round
Secondary magnification:	4.75x (net Cassegrain focal length 210 cm)
Back focal distance:	30.0 cm

The filter wheel contains two clear apertures and 8 filters. The filters include duplicates of some of the medium-band filters in the High Resolution Images and filters that isolate OH, CN, and C2 as well as the green and violet continuum. These narrow-band filters are designed to match the Hale-Bopp filter sets used for ground-based programs since 1996. The longest wavelength filter is actually a long-pass filter that uses the CCD response to define the long-wavelength cutoff at about 960 nanometers.

The detector is a 1024 x 1024 split-frame, frame-transfer CCD with 21-micron-square pixels. The electronics allows readout of centered sub-frames in multiples of 2: 64x64, 128x128, and so on, with or without rows of overscan. Transfer time, to move the two halves of the image from the exposing area to the two shielded areas, is about 5.2 milliseconds. There are readout amplifiers in each of the four quadrants. Readout time for a full frame is about 1.8 seconds. Net pixel scale is 10 microradians/pixel (2 arcseconds/pixel).

The MRI instrument in full-frame 1024 x 1024 mode has the following field-of-view characteristics:

Pixel Size:	21 micrometers
Pixel FOV:	10.0 microradians or 2.06265 arcseconds
Instrument FOV:	10.0 milliradians or 0.587 degrees
Surface Scale:	7 meters/pixel at 700 kilometers

The MRI instrument includes an internal stimulator lamp for calibrating between the four quadrants of the CCD; it is not a standard calibrator.

The three instruments on the flyby spacecraft, MRI, HRII (High Resolution IR Imaging Spectrometer), and HRIV (High Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned as described by Klaasen, et al. (2008) [7].

For navigation imaging [9], an MRI observation is typically snipped into one, or more, smaller rectangular areas containing the target(s) of interest reduce the download time. This processing is performed onboard the spacecraft, and the snips for each observation are downloaded as individual packets. The Deep Impact Science Data Center at Cornell University reconstructs the packets for each observation into the original, raw, 1008x1008 pixel image, without overclock rows and columns [7].

For a detailed discussion of the instrument and how it was used during the Deep Impact mission, see Hampton, et al. (2005) [4] and Klaasen, et al. (2005) [12]. For the EPOXI mission, the MRI instrument is used primarily during the encounter with comet 103P/Hartley 2.

Instrument Calibration

The MRI instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during a thermal-vacuum test (TV4) performed in 2003. In-flight calibrations continue through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. (2008) [7].

Calibration analysis combining Deep Impact and early EPOXI data determined the two halves of the MRI CCD - the boundary being the two horizontal central lines 511 and 512 (zero based) - while physically consistent across the boundary, are biased during integration so that the centers of the two halves are apparently 1/6 pixel closer to the center, and the two boundary rows show a decrease in sensitivity of 1/6. Reconstructed image files space all lines evenly, so the true image is erroneously vertically pushed apart by 1/3 pixel at its center in these reconstructions. When making science measurements from HRIV images, one must therefore be very careful to properly account for the two flaws introduced by the apparently narrow central lines on the CCD - a geometric error that separates the image by an extra 1/3 pixel at the horizontal quadrant boundary, and 2) insertion of extra total radiance into calibrated images due to the flat-field correction, which corrects for an apparent radiance deficit in the two central rows because of the smaller number of photons actually incident on those rows.

Flight Performance

The MRI instrument generally performed as expected during flight. However calibration data acquired in 2008 for EPOXI show changes to the electronic crosstalk between the CCD quadrants since 2005. Therefore new crosstalk coefficients were calculated and incorporated into the calibration pipeline for EPOXI processing.

EPOXI Observations

Sections 3.2.1, 3.2.2, and 3.2.3describe the MRI observations for EPOXI.

2.3.3 CCD Imaging Modes

The imaging modes for the HRIV and MRI CCD instruments are provided in Table 2. Modes where the light blocker opens and closes are identified by 'shuttered' in the Mode column. Modes where the light blocker remained open for each image are identified by 'unshuttered'.

#	Mode Mnemonic	Mode	Stored Image Size (x & y)	# Serial Over-Clock Cols (x)	# Parallel Over-Clock Rows (y)	Minimum Commanded Exposure (ms)	Frame to Frame Time (sec)
1	FF	Full Frame (shuttered)	1024	8	8	0	1.634
2	SF1	Sub-Frame 1 (shuttered)	512	4	4	0	0.737
3	SF2S	Sub-Frame 2 (shuttered)	256	4	4	0	0.430
4	SF2N	Sub-Frame 2 (unshuttered)	256	4	4	4	0.232
5	SF3S	Sub-Frame 3 (shuttered)	128	2	2	0	0.312
6	SF3N	Sub-Frame 3 (unshuttered)	128	2	2	4	0.113
7	SF4O	Sub-Frame 4 (unshuttered)	64	0	1	4	0.062
8	SF4NO	Sub-Frame 4 (unshuttered)	64	0	0	4	0.062
8	FFDITH	Diagnostic (shuttered)	1024	8	8	0	1.634

Table 2 - Visible CCD (HRIV and MRI) Imaging Modes

The CCD arrays have several serial overclock columns (line samples) and several parallel overclock rows (lines) located around the edge of the array and the resulting images. **Pixels in the overclock areas are excluded from the MINIMUM and MAXIMUM values in the PDS labels.** See Hampton, et al. 2005 [4] for more details about the instrument modes and the overclock rows and columns.

2.3.4 CCD Filters

The filter characteristics for the HRIV and MRI CCD instruments are shown in Table 3. The characteristics of the filters for the HRIV and MRI instruments were:

Filter Wheel Position	**MRI Center Wavelength (nm)**	**MRI Filter Width (nm)**	**MRI Filter Target Measurement**	**HRI Center Wavelength (nm)**	**HRI Filter Width (nm)**
1	650	>700[a]	Context	650	>700[a]
2	514	11.8	C2 in coma	450	100
3	526	5.6	Dust in coma	550	100
4	750	100	Context	350	100[c]
5	950	100[b]	Context	950	100[b]
6	650	>700[a]	Context	650	>700[a]
7	387	6.2	CN in coma	750	100
8	345	6.8	Dust in coma	850	100
9	309	6.2	OH in coma	650	100

[a]Filters in position 1 & 6 are uncoated fused silica and not band limited.
[b]The 950 nm filter is longpass.
[c]The coating on the 350 nm filter is shortpass; the substrate limits the short wavelength to about 320 nm. The dichroic beamsplitter limits the short cutoff to about 300 nm (for HRI only).

Table 3 - HRIV and MRI Filters

3 Archive Overview

3.1 Data Set and Data Volume Organization

For the EPOXI archive, the science data products generated by the SDC pipeline are grouped into PDS data sets by target (EPOCh exoplanet transits, EPOCh Earth, EPOCh Mars (planned), comet Hartley 2, or calibrations), instrument (HRII, HRIV, or MRI), and reduction level (raw or calibrated). The EPOXI science data sets are organized using the subdirectories recommended by the PDS standards:

- BROWSE (optional)
- CALIB
- CATALOG
- DATA
- DOCUMENT
- GEOMETRY (optional)
- INDEX

3.1.1 BROWSE Directory

The BROWSE directory is optional. If present, the BROWSE directory for an EPOCh data set contains one JPEG image for each target. If present for the DIXI encounter data sets, the BROWSE directory contains an 80x40-pixel thumbnail file and a full-size JPEG file of each image found in the DATA directory and are grouped by the observation day of year.

3.1.2 CALIB Directory

The CALIB directory is included only in the calibrated data sets and provides the files used by the SDC pipeline to calibrate raw data for the exoplanet transit, Earth, and Mars (planned) observations for EPOXI and the DIXI Hartley 2 observations. The PROCESSING_HISTORY_TEXT keyword in the PDS data labels lists the calibration files from the CALIB directory that the pipeline used.

The EPOXI science team produces the calibration files as a result of analyses of thermal-vacuum and in-flight calibration data from Deep Impact and in-flight calibrations acquired during EPOXI.

3.1.3 CATALOG Directory

The CATALOG directory contains catalog files required by PDS:

- DATASET.CAT - Description of the data set (required reading)
- DIF.CAT - Description of the Flyby spacecraft
- <instrument.CAT> - Description of each instrument: HRII.CAT, HRIV.CAT or MRI.CAT
- EPOXI.CAT - Description of the mission
- PERSON.CAT - Contact information for personnel who created the data set
- REF.CAT - List of publications cited in the catalog files
- <target>.CAT - One file for each mission target, for example, HAT_P_2.CAT, XO_3.CAT, EARTH.CAT, and 103P_HARTLEY_2_1986_E2.CAT.
- CALIBRATION.CAT - Generic catalog file for all calibration targets, where the TARGET_DESC keyword in the PDS data labels provides the specific target name such as CANOPUS or DARK.

3.1.4 DATA Directory

The DATA directory contains the raw or calibrated science image data grouped by level of calibration, by target, then by the year and day of year of the UTC mid-point of the observation:

<DATA>/<level><target>/<year>/<day of year>

where:

- level is RADREV for calibrated but uncleaned data in units of radiance (calibration steps can be reversed to get back to the raw DN) or RAD for calibrated and irreversibly cleaned data in units of radiance; the RADREV and RAD products from the HRIV and MRI CCDs include a multiplicative factor for converting from units of radiance to I-over-F (unitless)
- target is only used for raw and calibrated EPOCh exoplanet observations data sets
- year is 4 digits
- day of year is 3 digits

3.1.5 DOCUMENT Directory

The DOCUMENT directory provides documentation, supplementary, and ancillary information pertaining to the raw and calibrated science data sets and nominally includes:

- Project documents listed in section 1.2.2
- Image parameters tables when available
- A description of the quaternion found in the PDS labels
- Perpetual and leap year day-of-year calendars
- A report about the known limitations of the IR calibration pipeline and the resulting reduced data
- The IDL programs used for the calibration pipeline (provided only as documentation; the programs are not supported)

- The EPOXI local Data Dictionary which consists of the full PDS Data Dictionary plus keywords specific to EPOXI, such as EPOXI:IMAGE_MID_TIME
- The EPOXI Data Management and Archive Plan [3]
- This Software Interface Specifications Document

Documentation for Deep Impact was extensive. Instead of duplicating documents for each Deep Impact data set, all documentation was gathered into a separate PDS data set for the Deep Impact archive, DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V1.0. Since documentation for EPOXI complements that for Deep Impact, all EPOXI documentation will be gathered and included in an updated version of the Deep Impact and EPOXI Documentation Data Set, DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V2.0.

3.1.6 GEOMETRY Directory

The GEOMETRY directory is optional and is typically not included if a PDS data set of SPICE kernels is delivered. However the project may include ASCII text tables of improved geometry and timing values for each observation if the corresponding values in the data product labels are based on older SPICE kernels.

3.1.7 INDEX Directory

This directory contains a comma-separated, fixed-width, ASCII table for locating data products within the data directory. Index files are required by PDS and include some values found in the data label that are relevant to science, such as TARGET_NAME and START_TIME.

3.2 Expected Data Sets

3.2.1 In-Flight Calibrations

All raw (EDR), in-flight calibration data acquired during the various phases of the EPOXI mission will be accumulated over time and grouped into data sets by instrument for the PDS archive. In-flight calibrations include:

- Lunar observations acquired during flybys of Earth by all three instruments,
- HRIV darks and STIM lamp frames to aid calibration of the EPOCh exoplanet transit and Earth observations,
- Standard EPOXI cruise calibrations for all three instruments, and
- Additional calibrations designed to further test or retest a specific instrument or observing scenario, such as instrument checkout, as described in the DATASET.CAT file in the CATALOG directory.

Instr. ID	Data Set ID	Volume Set ID	Data Products
HRII	DIF-CAL-HRII-2-EPOXI-CALIBRATIONS-V1.0	EPXCAL_0001	EDR: Raw, in-flight calibrations
HRIV	DIF-CAL-HRIV-2-EPOXI-CALIBRATIONS-V1.0	EPXCAL_0002	EDR: Raw, in-flight calibrations
MRI	DIF-CAL-MRI-2-EPOXI-CALIBRATIONS-V1.0	EPXCAL_0003	EDR: Raw, in-flight calibrations

For these data sets, the TARGET_NAME in the PDS labels is always set to the value "CALIBRATION". The actual name of the target such as "CANOPUS" or "DARK" is provided by the TARGET_DESC keyword in the labels.

If the SDC pipeline is modified after version 1.0 of the calibration data sets are delivered to PDS for review in 2009, then the project will redeliver all calibration-related data as version 2.0 at a later time. Also raw calibration data are acquired for the DIXI phase of the mission will be appended to the most current version of these data sets, and the version number will be incremented.

3.2.2 EPOCh

For the EPOCh phase of the mission, the following types of data will be archived by instrument into data sets by the reduction level:

- Raw (EDR) observations of eight stars with known transits by extra-solar planets as acquired by the HRIV instrument: Time series of continuous 50-second integrations were used with the clear #6 filter to observe each system for about three weeks, typically covering five or more transits as well as secondary eclipses.

- Calibrated RADREV (RDR) observations of eight stars with known transits by extra-solar planets as acquired by the HRIV instrument,

- Raw (EDR) observations of Earth as acquired by the HRII, HRIV, and MRI instruments,

- Calibrated RADREV and RAD (RDR) observations of Earth as acquired by the HRII, HRIV, and MRI instruments. As noted in section 3.1.4, the RADREV and RAD products for HRIV and MRI include a multiplicative factor for converting from units of radiance to I-over-F (unitless),
- Raw (EDR) observations of Mars ***if*** acquired by the HRII and HRIV instruments, and
- Calibrated RADREV and RAD (RDR) observations of Mars ***if*** acquired by the HRII and HRIV instruments. As noted in section 3.1.4, the RADREV and RAD products for HRIV include a multiplicative factor for converting from units of radiance to I-over-F (unitless).

The stars observed for exoplanet transits are:

- GJ 436
- HAT-P-4
- HAT-P-7
- TRES-2
- TRES-3
- WASP-3
- XO-2
- XO-3

The EPOCh data sets are:

Instr. ID	Data Set ID	Volume ID	Data Products
HRIV	DIF-X-HRIV-2-EPOXI-EXOPLANETS-V1.0	EPXEXO_0001	EDR: Raw exoplanet transit observations grouped by target, then mid-observation date
	DIF-X-HRIV-3-EPOXI-EXOPLANETS-V1.0	EPXEXO_0002	RDR: Calibrated (RADREV only) exoplanet transit observations, grouped by target then mid- observation date
HRII	DIF-E-HRII-2-EPOXI-EARTH-V1.0	EPXEAR_0001	EDR: Raw Earth observations grouped by mid- observation date
	DIF-E-HRII-3/4-EPOXI-EARTH-V1.0	EPXEAR_0002	RDR: Calibrated (RADREV and RAD) Earth observations grouped by mid-observation date
HRIV	DIF-E-HRIV-2-EPOXI-EARTH-V1.0	EPXEAR_0003	EDR: Raw Earth observations grouped by mid-observation date
	DIF-E-HRIV-3/4-EPOXI-EARTH-V1.0	EPXEAR_0004	RDR: Calibrated (RADREV and RAD) Earth observations grouped by reduction level then mid-observation date. The HRIV labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
MRI	DIF-E-MRI-2-EPOXI-EARTH-V1.0	EPXEAR_0005	EDR: Raw Earth observations grouped by mid-observation date

	DIF-E-MRI-3/4-EPOXI-EARTH-V1.0	EPXEAR_0006	RDR: Calibrated (RADREV and RAD) Earth observations grouped by reduction level then mid-observation date. The MRI labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
HRII	DIF-M-HRII-2-EPOXI-MARS-V1.0	EPXMAR_0001	EDR: ***If acquired***, raw Mars observations grouped by mid-observation date
	DIF-M-HRII-3/4-EPOXI-MARS-V1.0	EPXMAR_0002	RDR: ***If acquired***, calibrated (RADREV and RAD) Mars observations grouped by mid-observation date
HRIV	DIF-M-HRIV-2-EPOXI-MARS-V1.0	EPXMAR_0003	EDR: ***If acquired***, raw Mars observations grouped by mid-observation date
	DIF-M-HRIV-3/4-EPOXI-MARS-V1.0	EPXMRE_0004	RDR: ***If acquired***, calibrated (RADREV and RAD) Mars observations grouped by reduction level then mid-observation date. The HRIV labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.

If the SDC pipeline is modified after version 1.0 of these data sets are delivered to PDS for review in 2009, then the project will redeliver data sets as version 2.0 at a later time. Also additional Earth observations acquired after 2008 will be appended to the most current version of the Earth data sets, and the version number will be incremented

3.2.3 DIXI

During the DIXI phase of the mission, the following types of data will be acquired and archived by instrument into DIXI-specific data sets of raw data (EDR) and calibrated data (RDR – RADREV and RAD with a multiplicative factor in the labels for converting CCD radiance data to unitless I-over-F):

- Approach imaging of comet 103P/Hartley 2 by the HRIV and MRI CCDs beginning about 60 days before the encounter (E-60) and by the HRII spectrometer beginning about E-34 days,
- Imaging of comet 103P/Hartley 2 by all three instrument during the flyby encounter, and
- Lookback imaging of Hartley 2 by all three instrument extending to 21 days after the encounter (E+21).

The DIXI science data sets are:

Instr. ID	Data Set ID	Volume ID	Data Products
HRII	DIF-C-HRII-2-EPOXI-HARTLEY2-V1.0	EPXENC_0001	EDR: Raw Hartley 2 observations grouped by mid- observation date
	DIF-C-HRII-3/4-EPOXI-HARTLEY2-V1.0	EPXENC_0002	RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date
HRIV	DIF-C-HRIV-2-EPOXI-HARTLEY2-V1.0	EPXENC_0003	EDR: Raw Hartley 2 observations grouped by mid-observation date
	DIF-C-HRIV-3/4-EPOXI-HARTLEY2-V1.0	EPXENC_0004	RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date. The HRIV labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
MRI	DIF-C-MRI-2-EPOXI-HARTLEY2-V1.0	EPXENC_0005	EDR: Raw Hartley 2 observations grouped by mid-observation date
	DIF-C-MRIV-3/4-EPOXI-HARTLEY2-V1.0	EPXENC_0006	RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date. The MRI labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.

During the DIXI phase of the mission, the MRI CCD and occasionally the HRIV CCD will be used as navigation cameras. Navigation (Nav) images of comet 103P/Hartley 2 acquired during approach and encounter will be archived in the raw and calibrated (RADREV only) data sets listed below.

Instr. ID	Data Set ID	Volume ID	Data Products
HRIV	DIF-C-HRIV-2-NAV-EPOXI-HARTLEY2-V1.0	EPXNAV_0001	EDR: Raw Nav images of Hartley 2 grouped by mid-observation date
	DIF-C-HRIV-3-NAV-EPOXI-HARTLEY2-V1.0	EPXNAV_0002	RDR: Calibrated (RADREV only) Nav images of Hartley 2 grouped by mid-observation date
MRI	DIF-C-MRI-2-NAV-EPOXI-HARTLEY2-V1.0	EPXNAV_0003	EDR: Raw Nav images of Hartley 2 grouped by mid-observation date
	DIF-C-MRI-3-NAV-EPOXI-HARTLEY2-V1.0	EPXNAV_0004	RDR: Calibrated (RADREV only) Nav images of Hartley 2 grouped by mid-observation date

3.2.4 Higher-Level Data Sets for EPOCh and DIXI

Several higher-level products such as instrument temperatures, photometry tables, shape models, and SPICE kernels generated by the mission or the science teams are expected to be archived into the PDS. The proposed data sets are listed below. These data sets are typically simple and self-explanatory and are thus not described in this document.

Instr. ID	Data Set ID	Volume ID	Data Products
HRII, HRIV, MRI (and ITS)	DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V2.0	DIDOC_0002	Deep Impact and EPOXI documentation.
HRII, HRIV, MRI	DIF-C/E/X-SPICE-6 -V1.0	EPXSP_0001	SPICE kernels for the EPOXI mission.
HRII, HRIV, MRI	DIF-CAL-HRII/HRIV/MRI-6-EPOXI-TEMPS-V1.0	EPXTMP_0001	ASCII tables of averaged instrument sensor temperatures from telemetry
HRIV	DIF-X-HRIV-4-EPOXI-EXOPLANETS-V1.0	EPXEXO_0003	Calibrated and cleaned (e.g., deconvolved) EPOCh observations of exoplanet transits
HRIV	DIF-X-HRIV-5-EPOXI-EXOPLANET-PHOTOM-V1.0	EPXEXO_0004	ASCII table of photometry derived from EPOCh observations of exoplanet transits
HRIV	DIF-X-HRIV-4-EPOCH-EARTH-V1.0	EPXEAR_0007	Calibrated and cleaned (e.g., deconvolved) EPOCh observations of Earth
HRIV	DIF-E-HRIV-5-EPOCH-EARTH-PHOTOM-V1.0	EPXEAR_0008	ASCII table of photometry derived from EPOCh observations of Earth
HRII	DIF-E-HRII-5-EPOCH-EARTH-SPECT-MAPS-V1.0	EPXEAR_0009	Spectral maps derived from HRII EPOCh observation of Earth
HRIV, MRI	DIF-C-HRIV/MRI-5-HARTLEY2-SHAPE-V1.0	EPXENC_0007	Shape model of comet 103P/Hartley 2 derived from HRIV and MRI images
HRII	DIF-C-HRII-5-HARTLEY2-THERMAL-MAPS-V1.0	EPXENC_0008	Temperature maps of the surface of 103P/Hartley 2 derived from HRII spectra
MRI	DIF-C-MRI-5-HARTLEY2-PHOTOMETRY-V1.0	EPXENC_0009	ASCII table of photometry derived from MRI science and Nav images of 103P/Hartley 2

4 Science Data Products

This section describes of the raw Level 2 (EDR) and the calibrated Level 3 and 4 (RDR) data products generated by the SDC pipeline and included in the science data sets listed previously in sections 3.2.1, 3.2.2, and 3.2.3. We define science data products as the raw and calibrated HRII spectral and HRIV and MRI CCD visible image data acquired during the entire EPOXI mission as well as the HRIV and MRI CCD images acquired for navigation purposes during the DIXI phase of the mission.

4.1 Overview of Data Products

4.1.1 Raw FITS Data Product (EDR)

A raw science data product consists of a detached PDS label that points to a FITS file composed of 1) a two-dimensional primary image array with a header and 2) a two-dimensional image extension with a header that provides a pixel-by-pixel quality map. In particular,

> **For HRII:** The raw FITS file (*.fit) consists of a two-dimensional spectral image in units of data number (raw counts) and one image extension for a pixel-by-pixel quality flags map described in section 4.1.3. Fastest varying axis provides increasing wavelengths from about 1.05 to about 4.8 microns. The slowest varying axis is in the spatial direction.
>
> **For HRIV and MRI:** The raw FITS file (*.fit) consists of a two-dimensional CCD image in units of data number (raw counts) and one image extension for a pixel-by-pixel quality flags map described in section 4.1.3.

Raw data are archived as received on the ground, either as uncompressed (i.e., never compressed) or compressed integer data. Image data could be compressed by means of a look-up table that converted 14-bit data to 8-bit values onboard the spacecraft. Raw, compressed data are stored in the FITS files as FITS files as 8-bit unsigned integers (i.e., exactly as received on the ground).

For the HRII instrument, uncompressed data consist of 14-bit signed integers stored in the FITS files as 16-bit signed integers with no offset. For the HRIV and MRI instruments, uncompressed data consist of 16-bit unsigned integers stored in the FITS files as 16-bit signed integers with an offset of 32768. The byte order for all FITS files in this archive is most significant bit first (MSB).

One raw product is archived is archived for data of the EPOCh and DIXI targets (extrasolar targets, Earth, and Hartley 2) as well as for calibration data (e.g., dark frames and standard stars) acquired by the HRII, HRIV, and MRI instruments.

4.1.2 Calibrated FITS Data Product (RDR)

Identical to the raw science data product, a calibrated Level 3 or 4 data product also consists of a detached PDS label that points to a FITS file (*.fit) composed of 1) a two-dimensional primary image array with a header and 2) a two-dimensional image extension with a header that provides a pixel-by-pixel quality map and 3) additional two-dimensional image extensions depending on the instrument:

For HRII: The FITS file includes image extensions and headers for a spectral wavelength map, a spectral bandwidth map, and a signal-to-noise ratio map (*.fit). These extensions are described in sections 4.1.4 through 4.1.6.

For HRIV and MRI: The FITS file includes an image extension and header for a signal-to-noise ratio map, (*.fit). This extension is described in section 4.1.4.

The calibration process, described in section 3.2.1, creates three types of reduced data products (that is, primary image arrays and accompanying extension) that are archived for EPOXI:

RADREV: These Level 3 uncleaned radiance image data, designated by the mnemonic 'RADREV', are provided in units of radiance as Watts/(meter**2 steradian micron). These data are considered reversible because the applied calibrations can be removed to get back to the original, raw data numbers. This type of calibrated product is archived for data of the EPOCh and DIXI targets (extrasolar targets, Earth, and Hartley 2) acquired by the HRII, HRIV, and MRI instruments mission.

RAD: These Level 4, irreversibly cleaned, radiance data are designated by the mnemonic 'RAD' and are provided in units of radiance as Watts/(meter**2 steradian). These data have been cleaned in such a way (interpolation over bad pixels, cosmic ray removal, etc.) such that the applied calibrations cannot be backed out. This type of calibrated product is archived only for EPOCh Earth data and DIXI Hartley 2 data acquired by the HRII, HRIV, and MRI.

IFREV: An HRIV or MRI reversible radiance image (RADREV) can be converted to unitless I-over-F data by multiplying the RADREV image by the value provided by the EPOXI:DATA_TO_IOVERF_MULTIPLIER keyword in the PDS label (or the MULT2IOF keyword in the FITS header). This multiplier is only provided for HRIV and MRI data.

IF: An HRIV or MRI irreversible radiance image (RAD) can be converted to unitless I-over-F data by multiplying the RAD image by the value provided by the EPOXI:DATA_TO_IOVERF_MULTIPLIER keyword in the PDS label (or the MULT2IOF keyword in the FITS header). This multiplier is only provided for HRIV and MRI data.

Calibrated spectral and CCD image data are stored as 32-bit IEEE signed real numbers in the FITS files. The byte order is most significant bit first (MSB).

4.1.3 Quality Flags Map (FITS Extension)

The Quality Flags map is the first FITS header and image extension in a raw or reduced science data product. Produced by the SDC pipeline for HRII, HRIV, and MRI data, this extension provides one byte of eight data quality flags or bits for each pixel in the primary image array. The image extension has the same dimensions as the primary image array. Section 4.2.2 defines each bit flag, and section 5.7 explains how to use IDL to access the information in this map.

4.1.4 Signal-to-Noise Ratio Map (FITS Extension)

The Signal-to-Noise Ratio map is the last FITS header and image extension in a Level 3 or 4 calibrated science data product. Produced by the SDC calibration pipeline for HRII, HRIV, and MRI data, this extension provides the signal-to-noise ratio as calculated by the pipeline for each pixel in the primary image array. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers. Section 4.2.2 describes how the pipeline generates this extension.

4.1.5 IR Spectral Wavelength Map (FITS Extension)

The IR Spectral Wavelength map is the second FITS header and image extension in a Level 3 or 4 calibrated HRII science data product. Produced by the SDC calibration pipeline only for HRII data, this extension provides the spectral registration or wavelength for each pixel in the primary image. This extension is required because the wavelength for each pixel shifts with thermal changes within the instrument. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers. Section 4.2.2 describes how the pipeline generates this extension.

4.1.6 IR Spectral Bandwidth Map (FITS Extension)

The IR Spectral Bandwidth map is the third FITS header and image extension in a Level 3 or 4 calibrated HRII science data product. Produced by the SDC calibration pipeline only for HRII data, this extension provides the spectral bandwidth for each pixel in the primary image. This extension is required because the wavelength for each pixel shifts with thermal changes within the instrument. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers. Section 4.2.2 describes how the pipeline generates this extension.

4.1.7 Pipeline Calibration Files

Files used by the SDC pipeline to generate the calibrated science and navigation data products are produced by the EPOXI science team as a result of analyses of thermal-vacuum and in-flight calibration data from Deep Impact and in-flight calibrations from EPOXI.

Calibration files are provided as FITS image files (*.fit) or as flat ASCII tables (*.tab) with detached PDS labels and are packaged in the CALIB directory of the appropriate calibrated data sets. A PDS label for a calibrated science data product includes the PROCESSING_HISTORY_TEXT keyword that provides a list of the calibration files the pipeline used.

4.1.7.1 HRII Calibration Files

ABSCALIR - This subdirectory contains tables of the absolute calibration constants for all instrument (image) modes. The first column specifies the wavelength for the reading. The second column specifies the conversion factor for areas not under the anti-saturation filter. The last column contains the conversion factors for areas under the anti-saturation filter. Two identical files, one with a placeholder of '000' and another with '999' were created for the pipeline to allow existing processes to correctly execute.

ADCLUT - This subdirectory contains a look up table for the correction of uneven bit weighting caused by the analog-to-digital conversion. The single table applies to all instrument modes. As of this archive, the corrections had not been derived. Therefore, the input pixel values are the same as the output values to prevent the automated calibration pipeline from changing the data.

BADPIX - This subdirectory contains maps that identify bad pixels for all instrument modes. These are master maps where a pixel is flagged bad it was determined to be bad in the four in-flight science calibrations. Bad pixels are set to a value of 1. Also, the reference rows and columns around the edges of the array are set to 1. Good pixels are set to 0.

BIAS - This subdirectory contains a dummy bias correction map for each instrument mode. All bias maps are set to zero to prevent the automated calibration pipeline from changing data.

DECOMPRS - This subdirectory contains the four lossy look up tables used to decompress raw data.

DRKMODEL - This subdirectory contains master dark frames for all instrument modes.

FLAT - This subdirectory contains flat fields for all instrument modes. Version 1 flats with an effective date of 2005-01-12 are dummies (all one) because the pipeline requires a file if flat fielding is turned on. Several flats for instrument mode 4 were derived after a linearity correction was applied to each pixel (e.g., hriir_050112_3_4_0.fit, hriir_050510_1_4_0.fit, hriir_050607_1_4_0.fit, and hriir_050627_1_4_0.fit).

LINDN - This subdirectory contains mode-specific maps of the four coefficients used in a polynomial to linearize the raw data numbers. Mode 5 must use the mode 1 file. Modes 6 and 7 must use the mode 4 file.

PSF - This subdirectory contains a dummy point-spread function used by the calibration pipeline when one is not available. It is simply a centered delta function to prevent any changes to the data.

SPECMAP - This subdirectory contains temperature-dependent, pixel-by-pixel, spectral registration maps for each instrument mode. The first dimension provides the wavelength; the second provides the spectral resolution (delta wavelength). The temperature string in the file names refers to the temperature of the IR spectrometer for which a map is applicable.

SUNSPEC - This subdirectory contains two tables, based on different sources that provide the solar spectral irradiance at 1 AU for the given wavelengths.

XTALK - This subdirectory contains tables that specify the amount of gain from electronic cross talk that occurs between all possible combinations of the two quadrants of the IR array. There is one table for each instrument mode. The crosstalk between IR quadrants is negligible, thus the table values are set to zero to keep the automated calibration pipeline from changing data.

4.1.7.2 HRIV and MRI Calibration Files

ABSCALVS - This subdirectory contains ASCII text tables of the absolute calibration constants for all instrument (image) modes. The first column in a table specifies the constant for converting raw data numbers to units of radiance, W/(m**2 sr um). The second column specifies the constant for converting from units of radiance to units of reflectance (i.e., I-over-F or the observed radiance over the input solar radiance, unitless).

ADCLUT - This subdirectory contains a look up table for the correction of uneven bit weighting caused by the analog-to-digital conversion. The single table applies to all instrument modes. As of this archive, the corrections had not been derived. Therefore, the input pixel values are the same as the output values to prevent the automated calibration pipeline from changing the data.

BADPIX - This subdirectory contains maps that identify bad pixels for all instrument modes. Bad pixels are set to a value of 1. Good pixels are set to 0. Pixels in the serial and parallel overclock columns and rows are flagged as good (0). For each image mode, there is one row of warm pixels near the top and bottom edge. These rows are flagged as bad (1).

BIAS - This subdirectory contains bias correction maps for all instrument modes.

DECOMPRS - This subdirectory contains the four lossy look up tables used to decompress raw data.

DRKMODEL - This subdirectory contains master dark frames for all instrument modes.

FILTERS - This subdirectory contains one transmission profile table each HRIV or MRI filter.

FLAT - This subdirectory contains flat fields for every combination of instrument mode and filter.

PSF - This subdirectory contains maps of the point-spread function for all HRIV or MRI filters. For MRI, the PSF is simply a centered-delta function to prevent the pipeline from changing the data. For HRIV, the PSF files can be used to deconvolve an out-of-focus HRIV image. Also for HRIV, PSFs for each EPOCh extrasolar target and stellar calibration targets will be included if available.

XTALK - This subdirectory contains tables that specify the amount of gain from electronic cross talk that occurs between all possible combinations of the four quadrants of the CCD. There is one table for each instrument mode.

4.2 Data Product Generation and Labeling

4.2.1 Data Pipeline Overview

All raw and calibrated science data products (FITS files and PDS labels) described in this document are generated by a data and calibration pipeline that is maintained by the DI/EPOXI Science Data Center SDC at Cornell University. The pipeline takes raw telemetry with embedded data, as downloaded from the DI flyby spacecraft, and constructs raw FITS spectral or visible image files and PDS labels. Images that were compressed onboard the spacecraft are received on the ground in the compressed format. The data pipeline keeps the associated raw FITS images in the same compressed format, and these data are archived in the *compressed* format.

Next, the pipeline inputs the raw FITS files, decompresses any compressed data, calibrates the data through the RADREV and RAD streams, and outputs calibrated data as radiance FITS files (RADREV and RAD). For the HRIV and MRI instruments, the I/F stream in the pipeline calculates a multiplicative factor to convert a RADREV radiance image to unitless IFREV or RAD radiance image to unitless IF. This multiplicative factor is provided in the PDS labels (see section 4.1.2 for more information). The calibration process is briefly described below. For details about the SDC, the flow of data, and the calibration pipeline refer to the EPOXI Data Management and Archive Plan [3], Klaasen, et al. 2005 [5], and Klaasen, et al. 2008 [7].

Calibration files, such as bad pixel maps, are the result of various analyses by the science teams of ground-based thermal-vacuum and in-flight calibration data from Deep Impact as well as in-flight calibrations acquired throughout the EPOXI mission. Calibration files are stored at the DI/EPOXI SDC and are used by the calibration portion of the pipeline. The files used by the pipeline to calibrate raw HRII, HRIV, and MRI data are included in the reduced EPOXI data sets.

PDS data labels are generated by the data pipeline using information stored in the FITS primary and extension headers. All PDS data labels are detached.

4.2.2 Calibration Process

The initial version of the calibration process for the EPOXI mission uses the final version of the pipeline used to calibrate data from the Deep Impact mission, with several revisions due to analyses of calibration data acquired in 2008 for EPOXI:

- New bad pixel maps for HRII to account for an increase from 1.15% to 1.48% in the fraction of anomalous pixels since DI,
- New calibration constants for the HRIV 950-nm (#5) filter to account for a 6% increase of its response since DI, and
- New crosstalk coefficients both the HRIV and MRI instruments to account for changes in the electronic crosstalk between the CCD quadrants since DI.

The goal of the data calibration process for the HRII, HRIV, and MRI instruments is to:

- Convert the raw data numbers (DNs) returned from each pixel in each image or spectrum to absolute scientific units of scene radiance (reversible RADREV or irreversible RAD).
- Calculate a multiplicative factor to convert or scale HRIV and MRI radiance products (RADREV and RAD) to units of reflectance (I/F).
- Determine from where in the scene or its surroundings the photons originated that produced the signal in each pixel.

Please note that various steps within the calibration pipeline can be turned on or off. Therefore the DATASET.CAT file in the CATALOG directory of each calibrated data set provides a list of the processes that were active in the pipeline.

The analysis of thermal-vacuum and in-flight calibration data from Deep Impact and the resulting calibration pipeline is presented in the DI Calibration Pipeline paper by Klaasen, et al. 2008 [7] and in the DI Anticipated Flight Data publication by Klaasen, et al. 2005 [5]. The following excerpt from an incomplete draft of the DI Instrument Calibration paper [7] is provided here as an overview of the processing:

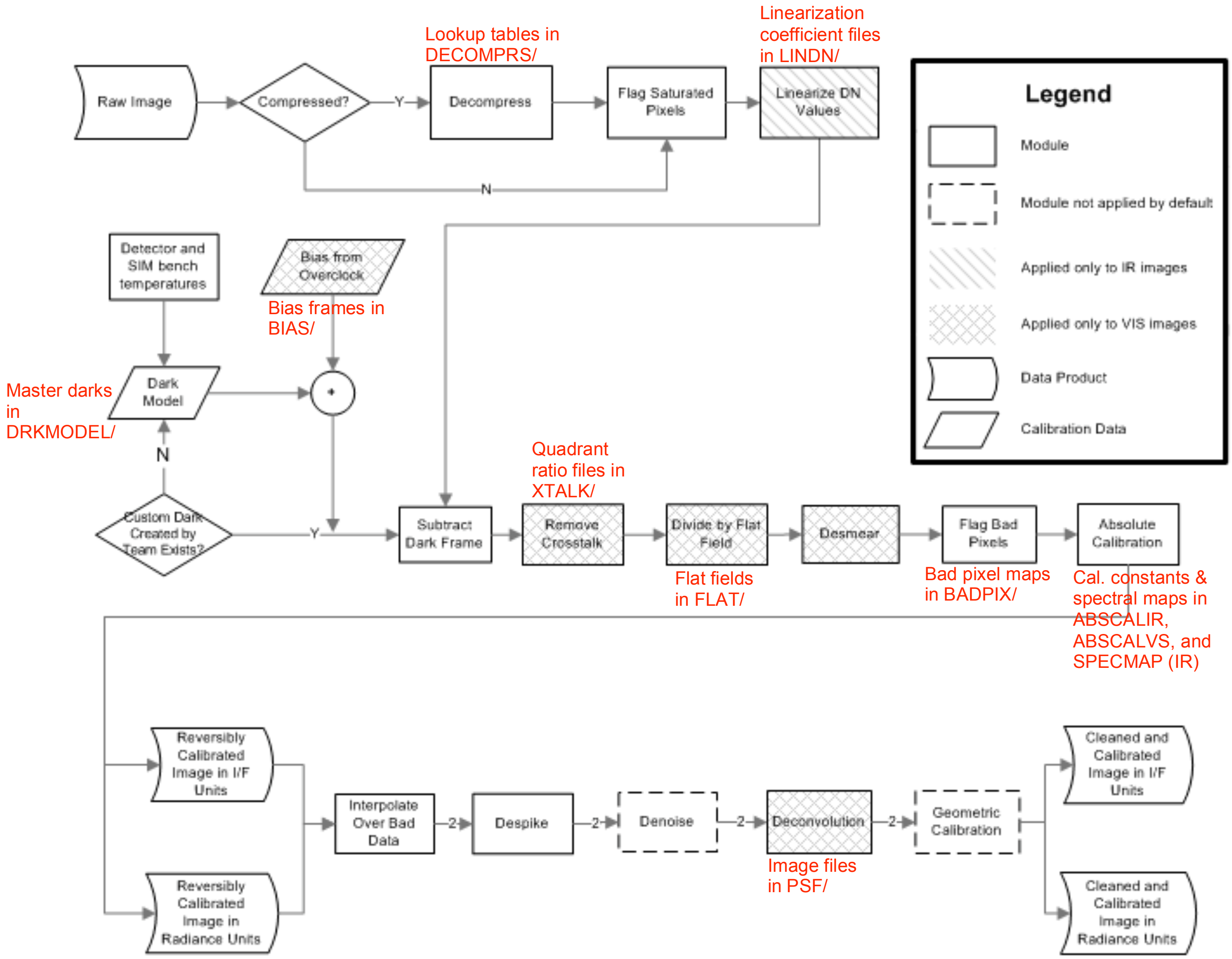

Figure 1 - A flowchart describing the data processing pipeline used to calibrate Deep Impact images. Some modules are not applied to all instruments. Input calibration files, such as the Look up tables for decompression, are identified by red text with the CALIB/ subdirectory (within a data set) included.

"6.0 Pipeline Processing

6.1 Standard Steps

For each image, there is a standard set of procedures and settings applied in our pipeline processing in order to calibrate the images automatically (see Figure 1). In general, these default settings are the best the science team has been able to derive for the data set as a whole and thus do not necessarily reflect the best possible processing for any particular image. However, there are some observations around encounter, especially with the IR spectrometer, that contain very valuable scientific information but are not processed optimally by the default settings. For these cases, the automated pipeline has the ability to specify special settings for particular observations.

The standard pipeline begins by decompressing the image if it was compressed on the spacecraft. Images can be compressed using one of four 14-bit to 8-bit look up tables optimized for different types of exposures. To uncompress the images, a reverse look up table is used which maps each 8-bit value to the average of all corresponding 14-bit values.

All saturated pixels are flagged in the quality map (Section 6.2 [7]). Then an IR image is linearized using the correction described in Section 5.3.1 [7]. A VIS image does not need this step because the instrument responds linearly (Section 4.3.1 [7]).

Next, a dark frame is subtracted from the image. If a dark frame has been created by the science team for the specific observation, then it is subtracted. Otherwise, a dark model is used to generate the frame (sections 4.3.3-VIS, 5.3.3-IR [7]; For a thorough discussion of dark pattern removal please see the published version of the DI Instrument Calibration paper [7]).

After the dark subtraction, a VIS image undergoes a few extra processing steps not taken by every IR image. First, the electrical crosstalk (Section 4.3.7.5 [7]) is removed by subtracting a derived ghost frame. Each quadrant in this frame is a linear combination of rotated versions of the other three quadrants. Next, the image is divided by a flat field (Section 4.3.6 [7]) in order to account for variable responsivity across the detector. A flat field is only applied to unbinned IR images because the best binned-mode flat field does not seem to provide any noticeable improvement in SNR (and in the data products published as PDS version 1, unbinned IR images are not flat fielded either). Lastly, VIS CCD transfer smear is removed using the parallel overclock rows if the image was taken in modes one through six or a column averaging approximation if the image is in modes seven or eight (Section 4.3.4 [7]).

After bad pixels are flagged, the image is radiometrically calibrated to produce a radiance image in W/[m^2 sr um] and an I/F image. For a VIS image, this is simply done by dividing the image by integration time and then multiplying by the appropriate conversion factor derived in Section 4.3.5 [7] for the given filter and desired output. For an IR image, the procedure is more complicated as the absolute calibration is wavelength dependent, which in turn is temperature dependent. First, the wavelength and bandwidth for each pixel are calculated as described in Section 5.3.4 [7]. Then, each pixel is multiplied by the appropriate wavelength-dependent calibration factor (Section 5.3.6 [7]) and divided by integration time and the pixel's spectral bandwidth. Once this radiance image is created, a copy is converted to I/F by dividing by the solar spectrum at the target's distance from the sun and then multiplying by pi.

At this point, two reversible data products have been created, one radiance image and one I/F image, and copies are run through the rest of the pipeline, which performs a series of non-reversible steps. First, the data are interpolated over the bad pixels and gaps. For a VIS image, this interpolation is performed using thin plate splines anchored by the valid data around the edges of each hole. For an IR image, a linear interpolation is performed in the spatial dimension only.

Next, a despiking routine is applied in order to remove cosmic rays. This routine performs a sigma filter by calculating the median of each NxN box, where N is odd, and then replacing the central pixel with the median if it is more than M median deviations from the median. By default, both M and N are set to 3. The median deviation of a set S is defined as:

$$Med\,(\,|\,\mathrm{S} - Med(\mathrm{S})\,|\,).$$

Lastly, a VIS image is deconvolved using the methods described in Section 4.2.3 [7]. This is especially important for the HRI-VIS instrument that is out of focus.

6.2 Calibration Quality Map

Along with each calibrated image, a byte map is created that defines the data integrity for every pixel. For each byte in the map, representing one pixel in the primary image array, each bit acts as a flag that is set to 1 if the given criterion is met for that pixel. These flags or bits are described next and are listed from the least-significant (0 or right-most) to most-significant (7 or left-most) within a byte:

MSB							LSB
7	6	5	4	3	2	1	0

0. Bad Pixel - This pixel is a known bad pixel.
1. Missing - The datum for this pixel was not received from the spacecraft.
2. Despiked - This pixel was modified by the despiking routine.
3. Interpolated - This pixel was reclaimed by interpolating from its neighbors.
4. Some Saturated - The ***raw*** value for this pixel is above the point where pixels are partially full-well saturated. For VIS instruments, this occurs at 11,000 DN, while for the IR spectrometer, this occurs at 8,000 DN.
5. Most Saturated - The ***raw*** value for this pixel is above the point where pixels are full-well saturated. For VIS instruments, this occurs at 15,000 DN, while for the IR spectrometer, this occurs at 11,000 DN. Bit flag 4 (above) will also be set in this case because raw value exceeded the limit for that flag, too.
6. ADC Saturation - The analog-to-digital converter (ADC) was saturated for this pixel.
7. Ultra Compressed - The ***raw*** value for this pixel was in a compression bin so large that the value contains very little useful information.

For example, if the pixel is bad and has been reclaimed by interpolation, the decimal value in the quality map will be $2^0 + 2^3 = 9$. In the normal FITS format for the calibrated image, this map exists as the first image extension.

For a raw image, only the missing data bit (#1) is turned on (set to 1). The remaining seven bits are set by the calibration pipeline for calibrated images only and are thus set to zero for all raw images.

6.3 Signal-to-Noise Ratio Map

In order to provide more information to the end user, the last extension of the image contains a map estimating the signal to noise ratio for each pixel. The signal is taken to be the dark- and bias-subtracted image value in 14-bit DN, while the noise estimate consists of the root-sum-squared of three different noise sources: shot noise, read noise and quantization noise. The shot noise in 14-bit DN is defined as:

$$N_s = \mathrm{sqrt}\,(\,(\,Raw - Bias\,)\ /\ K\,)$$

where K is the gain in electrons/14-bit DN and is dependent on the instrument and mode, and *Raw* and *Bias* are in 14-bit DN. For the IR spectrometer, *Bias* is 0 by definition except in Mode 6. The quantization noise is defined as:

$$N_q = Q\ /\ \mathrm{sqrt}\,(\,12\,)$$

where Q is the quantization step in 14-bit DN. For uncompressed data, Q depends on the ADC performance of the instrument (see Sec. 4.3.7.3 and Sec. 5.3.8.3 [7]), while for compressed data, Q is set to the bin size in the decompression look up table that the pixel used or to the uncompressed Q value, whichever is larger. The parameter values needed for the noise calculation were determined from ground-based testing of the instruments and are shown in Table 20.

Instrument	**K (e/DN_{14})**	**Uncompressed Q (DN_{14})**	**Read Noise (DN_{14})**
IR Unbinned	16	1	2.0
IR Binned	64	1	1.0
HRI	27.4	2	0.7
MRI	27.2	2	1.0
ITS	30.5	2	1.2

Table 20 - Noise parameters determined in ground tests of all instruments.

6.4 Spectral Registration Maps

In an IR image product, the second and third extensions are pixel-by-pixel maps of the spectral registration for the image. The second extension contains the effective wavelength of the pixel, while the third extension contains the spectral bandwidth. The calculations of these values are described in Section 5.3.4 [7].

6.5 Optional Steps

Beyond the automated calibration pipeline described in Section 6.1, a manual calibration can be performed where the user can specify his/her own settings and calibration files for each step. Also, any processing module can be disabled, and there are two extra ones that can be enabled. The first such module is a noise-reduction module that is applied after the despiking routine. This applies the BayesShrink wavelet thresholding algorithm with a robust mean noise estimator to remove some of the noise. The other step that can be enabled applies a rubber sheet geometric distortion correction. This is not normally applied as the optical distortion though the telescope is minimal."

See the instrument calibration document [7] for a detailed description of the image quality, spectral wavelength, spectral bandwidth, and signal-to-noise maps created by the pipeline and appended to the primary FITS image as image extensions.

4.2.3 Image Orientation and Pixel Readout Order

This section was excerpted from an incomplete draft of the DI Calibration Pipeline paper [7].

In order to understand the data from the instruments at the level of calibrations, it is important to understand both the way in which pixels are read out from the detector and also the way in which they are stored in the resultant FITS/PDS images. Throughout this paper we identify the four physical quadrants of the detectors as A through D (or just A and B in the case of the IR detector, which only uses 2 of the quadrants on the physical detector). The nomenclature in Figures 2a, 2b, and 3 assumes the standard convention for displaying FITS files: the faster-varying index in the data file (for line samples) is displayed to the right and the slower varying index (for lines) is displayed up (in PDS images the directions are controlled by keywords, which for our images are set to match the standard FITS display). Thus, the first byte of the FITS/PDS file appears in the lower-left corner of the window and the last byte in the FITS/PDS file appears in the upper-right. All FITS/PDS archival images are structured to display a true image of the sky, with arbitrary rotation about the center of the image (ecliptic north is to the right in this particular image), rather than a mirror image of the sky. The image header information in the downlinked data is always written in the first 100 bytes of quadrant A.

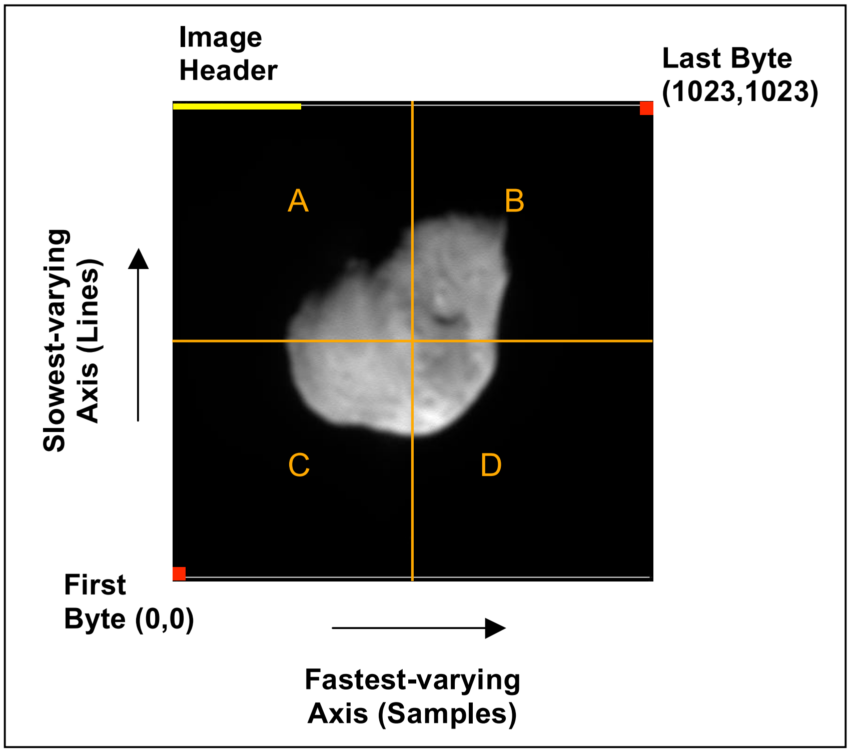

Figure 2a - A full-frame, HRI-VIS image taken shortly before impact, displayed with the FITS convention. This orientation reproduces a true sky image. The first and last bytes are those read from the FITS file and are not connected with the order of readout. Quadrants A, B, C and D noted throughout this paper are labeled in the image.

Figure 2a shows an inflight, visible image from HRI, in which the directions in the labels are referred to by the order of the bytes (pixels) in the archived data files. The images from the thermal-vacuum calibrations have the same orientation. For MRI, the different number of reflections in the optical path of the instruments lead to a right-left mirroring between the physical quadrants and the image of the sky and also a mirroring between the thermal-vacuum calibrations and the inflight data. Since the quadrant labeling refers to physical quadrants, the thermal-vacuum calibrations have the same orientation of the quadrants for all three instruments (A in upper left and D in lower right), but they have different orientations for inflight data, i.e., the inflight data for MRI have quadrant A in the upper right and quadrant D in the lower left for normally displayed FITS images. Thus the quadrants for inflight images from MRI are shown in Figure 2b.

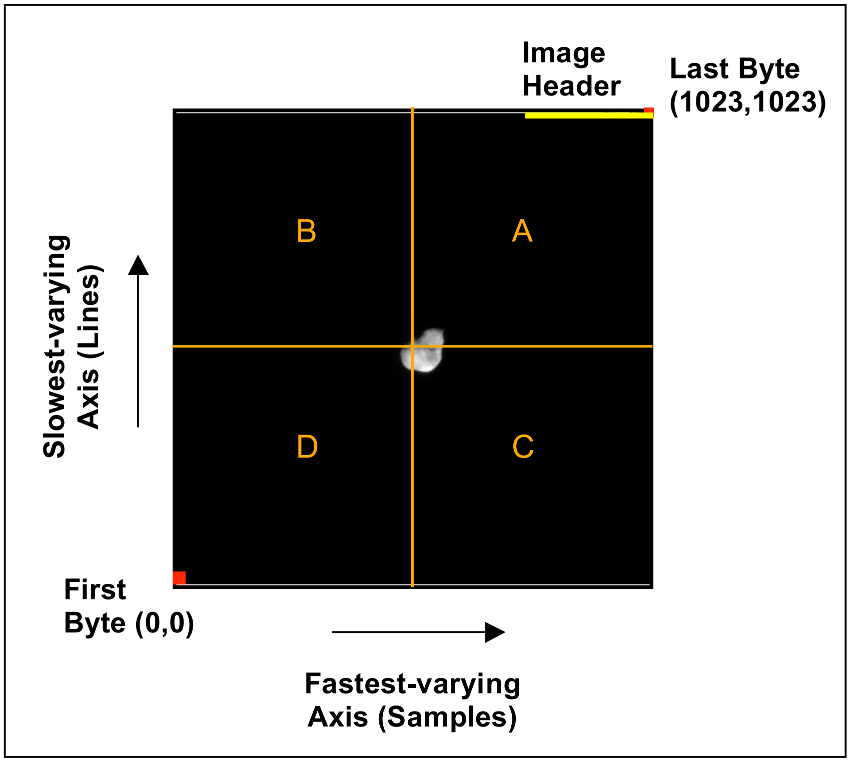

Figure 2b - A full-frame, MRI image taken at nearly the same time as the HRI-VIS image in Figure 2a. Displayed with the FITS convention, a true sky image is reproduced. The first and last bytes are those read from the FITS file and are not connected with the order of readout. Quadrants A, B, C and D noted throughout this paper are labeled in the image.

The readout order of the pixels is independent of the order of bytes in the FITS images since each quadrant is read out independently in parallel, and the bytes are then rearranged into an image. The direction of the split-frame rapid transfer is up and down in Figures 2a and 2b, symmetric about the centerline. This affects the smear of bright sources in short exposures. After shifting to the shielded region of the detector, the top and bottom rows are read out first (top and bottom of the relevant subframe when only a subframe is read), and in each of these rows the outermost pixels are read out first. The rows immediately above and below the centerline are read out last, and within these two rows, the pixels immediately adjacent to the centerline are read out last. The header information is overwritten on the first 100 bytes of quadrant A (upper left quadrant for HRI inflight images and upper right quadrant for in-flight images with MRI) after the image is constructed. Overclocked pixels and rows are read out after the true pixels, but they are moved to the outside of the FITS/PDS image to preserve the contiguity of the image in normal displays.

The situation for the IR spectrometer is shown in Figure 3. The normally displayed image, whether using the FITS standard display convention or displaying via the relevant PDS keywords, will have wavelength increasing from left to right and the long spatial dimension of the slit oriented vertically. The vertical spatial direction in the spectrometer image is the same as in the HRI visible image, terminator at the top and limb at the bottom for a spectrum at the time of Figure 2a. There are only two quadrants used (as shown in Figure 4), although the actual detector has two additional quadrants that are not exposed to light and are not read out. The orientation is the same both for inflight data and for thermal-vacuum calibrations, with A is on the left in a standard FITS/PDS display and B is on the right. When the image is constructed, the header information is overwritten on the first 100 bytes of quadrant A.

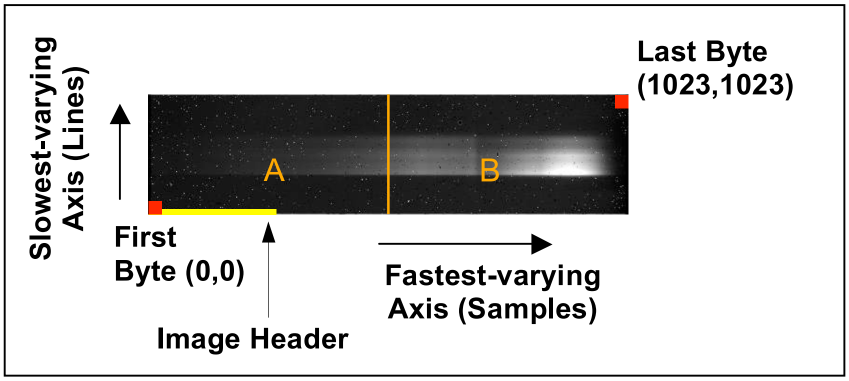

Figure 3 - A full-frame, HRIIR image taken shortly before impact, displayed with the FITS convention. For this FITS display, the wavelength increases as the fastest-varying axis increases to the right. The slowest-varying axis is the spatial direction along the slit. The first and last bytes are those read from the FITS file and are not connected with the order of readout. IR quadrants A and B noted throughout this paper are labeled in the image.

Since the IR detector is reset and read out on a pixel-by-pixel basis, the readout order affects the actual time at which a pixel is exposed, unlike the situation for the visible CCDs. Each pixel has the same exposure duration, but the exposure of the last pair of pixels read out does not start until one integration delay time plus ~2 ms before the first pair of pixels is read out. As with the lower half of the visible images, the bottom row is read out first, and within that row the outermost (leftmost and rightmost) pixels are read out first. The spectral row at the upper end of the slit in this standard display is read out last, and within that row the two pixels on either side of the center line are read out last. The header information is again written over the first 100 bytes of quadrant A, now in the lower left of a normal display.

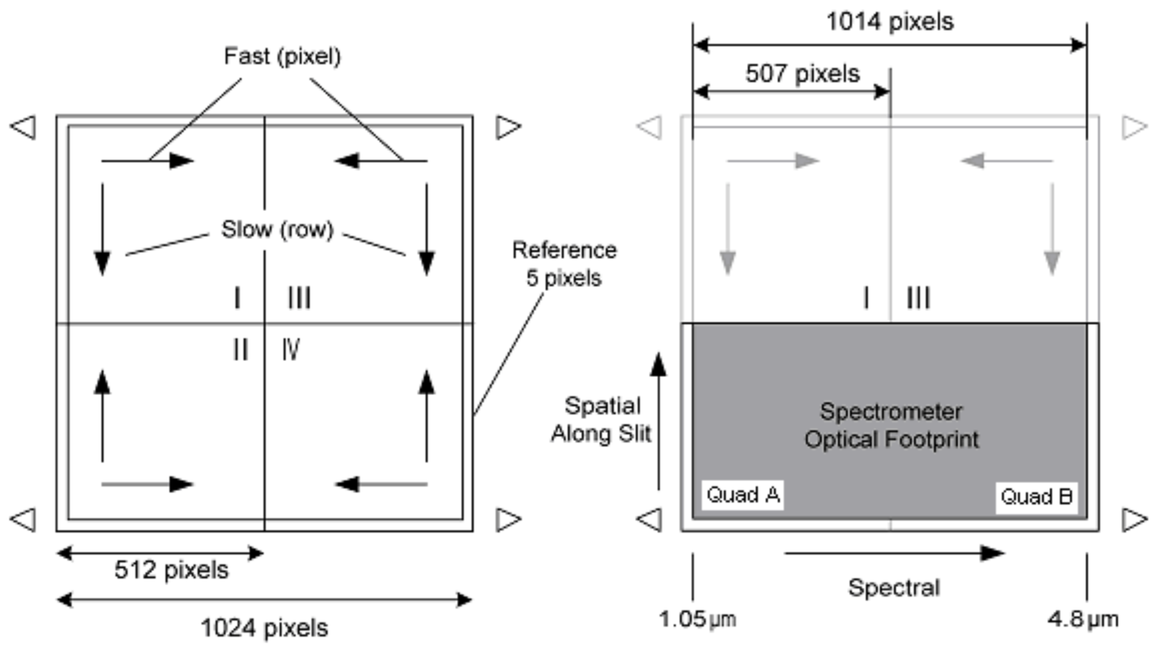

Figure 4 - IR focal plane array architecture ([4], used with permission). The left panel shows the architecture for the full IR FPA. The right panel shows the spectrometer mapping onto the FPA. Only Quads II (A) and IV (B) are used; Quads I and III are not used.

4.2.4 Data File Naming Conventions and Product IDs

The naming convention for the products in the data directory for the raw and calibrated data sets is:

iiYYMMDDHH_eeeeeee_nnn{_xx}.fit or .lbl

where:

- ii = instrument mnemonic: "hi" for the HRI IR Spectrometer, "hv" for the HRI Visible CCD, and "mv" for the MRI Visible CCD
- YYMMDDHH = Abbreviated UTC time stamp for the mid-point of the observation: YY is the last two digits of the year, MM is the month, DD is the day, and HH is the hour (00 to 23)
- eeeeeee = exposure ID
- nnn = image number within the exposure ID
- xx = identifies the level of calibration: "rr" for RADREV, "r" for RAD, and "if" for I-over-F (reflectance); not used for RAW

This convention guarantees unique file names within a PDS data set. The value for the PRODUCT_ID keyword in the PDS data labels is formed from the FITS file name where the period before the extension is replaced with an underscore character. PRODUCT_IDs are unique within each data set as required by PDS.

4.3 Standards Used in Data Product Generation

4.3.1 PDS Standards

The version 3, PDS3, of the PDS Standards Reference [1] and revision E of the PDS Data Dictionary and the EPOXI Local Data Dictionary [2] were followed when generating the data products.

4.3.2 Time Standards

Times given in the PDS labels are UTC at the EPOXI spacecraft, unless otherwise specified.

4.3.3 Reference Frame Standards

PDS labels for raw and calibrated science and navigation FITS data products contain keywords that provide geometry-related values based on the inertial reference frame, Earth mean equator J2000 (EMEJ2000). The exception is the ECLIP_NORTH_CLOCK_ANGLE keyword that is in the Ecliptic J2000 frame (ECLIPJ2000). Definitions of geometry keywords found in the raw and calibrated science and navigation labels are found in section 4.5 of this document.

4.3.4 Time- and Geometry-Related Keywords

All time-related keywords in the data labels, except EARTH_OBSERVER_MID_TIME, are based on the clock on board the flyby spacecraft. EARTH_OBSERVER_MID_TIME provides the UTC when an Earth-based observer should have been able to see an event recorded by the instrument.

The SDC pipeline was not able to automatically determine the proper geometric information for the target of choice in some cases. When these parameters could not be computed, the corresponding keywords in the data labels are set to a value of unknown, 'UNK'. Also if GEOMETRY_QUALITY_FLAG is set to 'BAD' or GEOMETRY_TYPE is set to 'PREDICTED' in the PDS labels, then this indicates the geometry values are not accurate and should be used with caution. The value 'N/A' is used for some geometry-related keywords in the data labels because these parameters are not applicable for certain calibration targets.

Observational geometry parameters provided in the data labels were computed at the epoch specified by the mid-obs UTC, IMAGE_MID_TIME, in the data labels. The exceptions are the target-to-sun values that were calculated for the time when the light arrived at the target and the earth-observer-to-target values that were calculated for the time when the light left the target.

4.3.5 Image Orientation

The raw and calibrated science and navigation FITS images in this PDS archive are those produced by the data pipeline and analyzed by the science team. These images are oriented such that the fastest-varying FITS axis (samples) increases to the right of and the slowest-varying FITS axis (lines) increases to the top such that the first pixel read from the FITS file is displayed in the lower-left corner of a graphics window and the last pixel in the upper-right. These sample and line directions are provided by the LINE_DISPLAY_DIRECTION and SAMPLE_DISPLAY_DIRECTION keywords in the PDS labels.

This orientation provides views “as seen” from the spacecraft and places ecliptic north approximately to the right and the sun towards the bottom for all images from the beginning of EPOXI through the approach and shield mode portions for the Hartley 2 encounter of DIXI. As the spacecraft comes out of shield mode, it will turn back and continue imaging the comet. Therefore, all DIXI lookback images have ecliptic north approximately to the left and the sun approximately towards the top. See section 4.3.2 for more information.

The directions to celestial north, ecliptic north, the Sun, and the body positive pole position (for Hartley 2 observations only) are provided in data labels by

CELESTIAL_NORTH_CLOCK_ANGLE, ECLIPTIC_NORTH_CLOCK_ANGLE, SUN_DIRECTION_CLOCK_ANGLE, and BODY_POSITIVE_POLE_CLOCK_ANGLE keywords and are measured clockwise from the top of the image when is displayed in the correct orientation defined by SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION. Please note the aspect of the North celestial pole in an image can be computed by adding 90 degrees to the boresight declination given by DECLINATION in the data labels.

Also it is important to note that the slit of the HRII spectrometer is oriented vertically such that the top of the slit in an HRII image corresponds to the top of an HRIV or MRI image.

4.4 Sample PDS Labels

This section provides sample PDS labels for raw and calibrated science data products for the HRII spectrometer and the HRIV and MRI CCDs.

4.4.1 Level 2 (Raw) HRII Science Data Product

The raw science data products for the HRII instrument have self-consistent formats. An example of a PDS label for a raw HRII FITS data file is provided below. Units for the primary image array are data number.

```
PDS_VERSION_ID   = PDS3
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 84

^HEADER = ("HI08052904_1001003_004.FIT",1)
^IMAGE = ("HI08052904_1001003_004.FIT",15)
^EXT_QUALITY_FLAGS_HEADER = ("HI08052904_1001003_004.FIT",61)
^EXT_QUALITY_FLAGS_IMAGE = ("HI08052904_1001003_004.FIT",62)

DATA_SET_ID          = "DIF-E-HRII-2-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID            = "HI08052904_1001003_004_FIT"
PRODUCT_CREATION_TIME = 2009-02-09T23:15:12
PRODUCT_TYPE          = "RAW"

/***** TIME INFORMATION *****/
START_TIME            = 2008-05-29T04:21:03.984
EPOXI:IMAGE_MID_TIME  = 2008-05-29T04:21:04.702
STOP_TIME             = 2008-05-29T04:21:05.420
```

```
START_JULIAN_DATE_VALUE = 2454615.6812961
MID_JULIAN_DATE_VALUE   = 2454615.6813044
STOP_JULIAN_DATE_VALUE  = 2454615.6813127
SPACECRAFT_CLOCK_START_COUNT      = "1/0265306167.104"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0265306168.032"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0265306168.216"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2008-05-29T04:23:49.914

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EARTHOBS"
EPOXI:OBSERVATION_DESC       = "RADIOMETRY; N/S SCANS 5B"
EPOXI:POINTING_DESC          = "IR EARTH SCAN B"
TARGET_NAME                  = "EARTH"
TARGET_DESC                  = "EARTH"
INSTRUMENT_MODE_ID           = 2
EPOXI:INSTRUMENT_MODE_NAME   = "BINSF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "1001003"
EPOXI:IMAGE_NUMBER     = "004"
EPOXI:COMMANDED_IMAGE_COUNT = 8
FILTER_NUMBER          = "N/A"
FILTER_NAME            = "N/A"
CENTER_FILTER_WAVELENGTH    = "N/A"
EPOXI:INTEGRATION_DURATION  = 1435.6400000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 304.1247840 <K>
, 304.1247840 <K>
, 299.3939680 <K>
, 302.5192480 <K>
, 283.5592160 <K>
, 163.1479276 <K>
, 137.5605760 <K>
, 137.2787488 <K>
, 132.1110720 <K>
, 135.9330490 <K>
, 83.9405000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2052597 <V>
```

```
, 1.2162471 <V>
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1058432 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0120705 <V>
, -9.2021797 <V>
, 0.2421531 <V>
, 0.7374664 <V>
, 3.4035968 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = "N/A"
VERTICAL_PIXEL_SCALE     = 495388.309 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE                         = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "OK"
EPOXI:GEOMETRY_TYPE               = "PREDICTED"
RIGHT_ASCENSION                  = 172.418745200 <DEG>
DECLINATION                      =   0.064255500 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE      = 112.5549 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE =  89.2999 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = 179.9771 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 112.5610 <DEG>
SOLAR_ELONGATION                 =  85.9196 <DEG>
PHASE_ANGLE                      =  75.065 <DEG>
TARGET_CENTER_DISTANCE           =   49538830.8946 <KM>
```

```
TARGET_HELIOCENTRIC_DISTANCE     =  151638590.527 <KM>
TARGET_GEOCENTRIC_DISTANCE       =          0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE   =  146888525.712 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE     =   49529487.895 <KM>
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                        =
(  0.683177600000
,  0.092082800000
, -0.700685400000
, -0.183927000000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
(  -4.919866894210e-05 <RAD/S>
,  -3.682750220260e-04 <RAD/S>
,  -1.543913646210e-04 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
(   49118869.452 <KM>
,   -6428890.231 <KM>
,    -319061.962 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
(   2.806568 <KM/S>
,   7.298245 <KM/S>
,   0.847287 <KM/S>
)
TARGET_SUN_POSITION_VECTOR        =
(   56669336.529 <KM>
,  129046247.358 <KM>
,   55945638.589 <KM>
)
TARGET_SUN_VELOCITY_VECTOR        =
( -27.144124 <KM/S>
,  10.326189 <KM/S>
,   4.477789 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR      =
(          0.000 <KM>
,          0.000 <KM>
,          0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR      =
(   0.000000 <KM/S>
,   0.000000 <KM/S>
,   0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR            =
(    7550467.077 <KM>
,  135475137.589 <KM>
,   56264700.551 <KM>
)
SC_EARTH_POSITION_VECTOR          =
(  -49109933.310 <KM>
,    6425187.955 <KM>
,     318717.944 <KM>
)
SUB_SPACECRAFT_LONGITUDE     =    41.0630015 <DEG>
```

```
SUB_SPACECRAFT_LATITUDE      =     -0.3225872 <DEG>
SUB_SOLAR_LONGITUDE          =   114.8285460 <DEG>
SUB_SOLAR_LATITUDE           =     21.6690802 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME       = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0265306168_1001003_004.FIT"
PROCESSING_HISTORY_TEXT      = "RAW"

OBJECT     = HEADER
  BYTES              = 40320
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 14
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 512
  LINES            = 128
  SAMPLE_BITS      = 16
  SAMPLE_TYPE      = "MSB_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET           = 0
  SCALING_FACTOR   = 1
  UNIT             = "DATA_NUMBER"
  EPOXI:DERIVED_MINIMUM            =  -126
  EPOXI:DERIVED_MAXIMUM            = 16168
  EPOXI:DERIVED_MEDIAN             =    986.0
  EPOXI:DERIVED_STANDARD_DEVIATION =    414.7
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
```

```
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT              = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 8
  SAMPLE_TYPE       = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_QUALITY_FLAGS_IMAGE

END
```

4.4.2 Level 2 (Raw) HRIV/MRI Science Data Product

The raw science data products for the HRIV and MRI instruments have self-consistent formats. Therefore, only an example of a PDS label for a raw HRIV FITS data file is provided below. Units for the primary image array are data number.

Labels for raw HRIV and MRI navigation images are identical to the example below, except several keywords in the FITS header do not exist because the flight software did not include the information in the minimal image headers.

```
PDS_VERSION_ID   = PDS3
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 291

^HEADER = ("HV08060416_1000001_001.FIT",1)
^IMAGE = ("HV08060416_1000001_001.FIT",16)
^EXT_QUALITY_FLAGS_HEADER = ("HV08060416_1000001_001.FIT",199)
^EXT_QUALITY_FLAGS_IMAGE = ("HV08060416_1000001_001.FIT",200)

DATA_SET_ID          = "DIF-E-HRIV-2-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID        = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HV08060416_1000001_001_FIT"
PRODUCT_CREATION_TIME = 2009-01-15T11:47:49
PRODUCT_TYPE         = "RAW"

/***** TIME INFORMATION *****/
START_TIME           = 2008-06-04T16:57:24.642
EPOXI:IMAGE_MID_TIME = 2008-06-04T16:57:24.649
STOP_TIME            = 2008-06-04T16:57:24.656
START_JULIAN_DATE_VALUE = 2454622.2065352
```

```
MID_JULIAN_DATE_VALUE   = 2454622.2065353
STOP_JULIAN_DATE_VALUE  = 2454622.2065354
SPACECRAFT_CLOCK_START_COUNT      = "1/0265869939.131"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0265869939.132"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0265869939.134"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2008-06-04T17:00:12.888

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EARTHOBS"
EPOXI:OBSERVATION_DESC       = "HRIV RADIOMETRY 1A"
EPOXI:POINTING_DESC          = "TO EARTH"
TARGET_NAME                  = "EARTH"
TARGET_DESC                  = "EARTH"
INSTRUMENT_MODE_ID           = 2
EPOXI:INSTRUMENT_MODE_NAME   = "SF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "1000001"
EPOXI:IMAGE_NUMBER     = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 1
FILTER_NUMBER          = 2
FILTER_NAME            = "BLUE"
CENTER_FILTER_WAVELENGTH    = 450 <NM>
EPOXI:INTEGRATION_DURATION  = 13.5000000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 303.9532000 <K>
, 303.9899680 <K>
, 296.2441760 <K>
, 302.0412640 <K>
, 283.4121440 <K>
, 163.2127061 <K>
, 137.3380562 <K>
, 137.1009052 <K>
, 131.8059846 <K>
, 135.7561008 <K>
, 84.1435000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2049545 <V>
, 1.2159419 <V>
```

```
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1106113 <V>
, 5.1050485 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0104812 <V>
, -9.2021797 <V>
, 0.2458221 <V>
, 0.7423583 <V>
, 3.4060428 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = 100893.168 <M/PIXEL>
VERTICAL_PIXEL_SCALE     = 100893.168 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE                         = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "OK"
EPOXI:GEOMETRY_TYPE               = "RECONSTRUCTED"
RIGHT_ASCENSION                  = 177.489792500 <DEG>
DECLINATION                      =  -0.215176100 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE      = 113.1337 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE =  89.7128 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = 180.0005 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 113.1357 <DEG>
SOLAR_ELONGATION                 =  84.1632 <DEG>
PHASE_ANGLE                      =  76.533 <DEG>
TARGET_CENTER_DISTANCE           =   50446583.8460 <KM>
TARGET_HELIOCENTRIC_DISTANCE     =  151789311.363 <KM>
```

```
TARGET_GEOCENTRIC_DISTANCE       =           0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE   =  148385381.127 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE     =   50436998.201 <KM>
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                        =
(  0.688178800000
,  0.126812100000
, -0.696991000000
, -0.156627400000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
(  -6.193104793090e-07 <RAD/S>
,   5.662622783320e-07 <RAD/S>
,  -2.666095006670e-06 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
(   50397729.649 <KM>
,   -2211519.755 <KM>
,     189336.499 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
(   1.724195 <KM/S>
,   7.629346 <KM/S>
,   0.946928 <KM/S>
)
TARGET_SUN_POSITION_VECTOR        =
(   41049886.647 <KM>
,  134075548.433 <KM>
,   58126148.701 <KM>
)
TARGET_SUN_VELOCITY_VECTOR        =
( -28.206501 <KM/S>
,   7.494698 <KM/S>
,   3.248512 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR      =
(          0.000 <KM>
,          0.000 <KM>
,          0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR      =
(   0.000000 <KM/S>
,   0.000000 <KM/S>
,   0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR            =
(   -9347843.002 <KM>
,  136287068.188 <KM>
,   57936812.202 <KM>
)
SC_EARTH_POSITION_VECTOR          =
(  -50388265.569 <KM>
,    2208512.122 <KM>
,    -189617.362 <KM>
)
SUB_SPACECRAFT_LONGITUDE     =   210.5053179 <DEG>
SUB_SPACECRAFT_LATITUDE      =      0.2619271 <DEG>
```

```
SUB_SOLAR_LONGITUDE          =   286.0135359 <DEG>
SUB_SOLAR_LATITUDE           =     22.5295803 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME       = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0265869939_1000001_001.FIT"
PROCESSING_HISTORY_TEXT      = "RAW"

OBJECT     = HEADER
  BYTES              = 43200
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 15
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 512
  LINES            = 512
  SAMPLE_BITS      = 16
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET           = 32768
  SCALING_FACTOR   = 1
  UNIT             = "DATA_NUMBER"
  EPOXI:DERIVED_MINIMUM            =   361
  EPOXI:DERIVED_MAXIMUM            =  5060
  EPOXI:DERIVED_MEDIAN             =    376.0
  EPOXI:DERIVED_STANDARD_DEVIATION =    278.7
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
```

```
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT              = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 512
  SAMPLE_BITS       = 8
  SAMPLE_TYPE       = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_QUALITY_FLAGS_IMAGE

END
```

4.4.3 Level 3/4 (Calibrated) HRII Science Data Product

The calibrated science data products for the HRII instrument have self-consistent formats. An example of a PDS label for a reversible, calibrated HRII FITS science image in units of radiance (RADREV, not cleaned) is provided below. Labels for RAD (radiance units, cleaned) science images have the same format.

```
PDS_VERSION_ID    = PDS3
RECORD_TYPE       = "FIXED_LENGTH"
RECORD_BYTES      = 2880
FILE_RECORDS      = 412

^HEADER = ("HI08052904_1001003_004_RR.FIT",1)
^IMAGE = ("HI08052904_1001003_004_RR.FIT",18)
^EXT_QUALITY_FLAGS_HEADER = ("HI08052904_1001003_004_RR.FIT",110)
^EXT_QUALITY_FLAGS_IMAGE = ("HI08052904_1001003_004_RR.FIT",111)
^EXT_WAVELENGTH_HEADER = ("HI08052904_1001003_004_RR.FIT",134)
^EXT_WAVELENGTH_IMAGE = ("HI08052904_1001003_004_RR.FIT",135)
^EXT_SPEC_BANDWIDTH_HEADER = ("HI08052904_1001003_004_RR.FIT",227)
^EXT_SPEC_BANDWIDTH_IMAGE = ("HI08052904_1001003_004_RR.FIT",228)
^EXT_SNR_HEADER = ("HI08052904_1001003_004_RR.FIT",320)
^EXT_SNR_IMAGE = ("HI08052904_1001003_004_RR.FIT",321)

DATA_SET_ID          = "DIF-E-HRII-3/4-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HI08052904_1001003_004_RR_FIT"
PRODUCT_CREATION_TIME = 2009-02-09T23:15:12
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2008-05-29T04:21:03.984
EPOXI:IMAGE_MID_TIME = 2008-05-29T04:21:04.702
STOP_TIME            = 2008-05-29T04:21:05.420
```

```
START_JULIAN_DATE_VALUE = 2454615.6812961
MID_JULIAN_DATE_VALUE   = 2454615.6813044
STOP_JULIAN_DATE_VALUE  = 2454615.6813127
SPACECRAFT_CLOCK_START_COUNT      = "1/0265306167.104"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0265306168.032"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0265306168.216"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2008-05-29T04:23:49.914

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EARTHOBS"
EPOXI:OBSERVATION_DESC       = "RADIOMETRY; N/S SCANS 5B"
EPOXI:POINTING_DESC          = "IR EARTH SCAN B"
TARGET_NAME                  = "EARTH"
INSTRUMENT_MODE_ID           = 2
EPOXI:INSTRUMENT_MODE_NAME   = "BINSF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "1001003"
EPOXI:IMAGE_NUMBER     = "004"
EPOXI:COMMANDED_IMAGE_COUNT = 8
FILTER_NUMBER          = "N/A"
FILTER_NAME            = "N/A"
CENTER_FILTER_WAVELENGTH    = "N/A"
EPOXI:INTEGRATION_DURATION  = 1435.6400000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 304.1247840 <K>
, 304.1247840 <K>
, 299.3939680 <K>
, 302.5192480 <K>
, 283.5592160 <K>
, 163.1479276 <K>
, 137.5605760 <K>
, 137.2787488 <K>
, 132.1110720 <K>
, 135.9330490 <K>
, 83.9405000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2052597 <V>
, 1.2162471 <V>
```

```
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1058432 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0120705 <V>
, -9.2021797 <V>
, 0.2421531 <V>
, 0.7374664 <V>
, 3.4035968 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = "N/A"
VERTICAL_PIXEL_SCALE     = 495388.309 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE                          = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "OK"
EPOXI:GEOMETRY_TYPE               = "PREDICTED"
SPICE_FILE_NAME    = ( "NAIF0009.TLS",
                       "PCK00008.TPC",
                       "DIF_SCLKSCET.00036.TSC",
                       "DI_V17.TF",
                       "DIF_HRI_V10.TI",
                       "DIF_MRI_V10.TI",
                       "DIF_PREDICT_050112_050809.BC",
                       "DIF_EPOXI_PREDICT_V20081206.BC",
                       "DIF_PRED_EARTHOBS4_1.BC",
                       "DIF_SC_050112_050809.BC",
```

```
                       "DIF_SC_050225_HIGHRATE.BC",
                       "DIF_SC_050704_HIGHRATE.BC",
                       "JUP164_20YEAR.BSP",
                       "SPK_OD221_FULL.BSP" )
RIGHT_ASCENSION                  = 172.418745200 <DEG>
DECLINATION                      =   0.064255500 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE      = 112.5549 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE =  89.2999 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = 179.9771 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 112.5610 <DEG>
SOLAR_ELONGATION                 =  85.9196 <DEG>
PHASE_ANGLE                      =  75.065 <DEG>
TARGET_CENTER_DISTANCE           =   49538830.8946 <KM>
TARGET_HELIOCENTRIC_DISTANCE     =  151638590.527 <KM>
TARGET_GEOCENTRIC_DISTANCE       =          0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE   =  146888525.712 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE     =   49529487.895 <KM>
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                        =
(  0.683177600000
,  0.092082800000
, -0.700685400000
, -0.183927000000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
(  -4.919866894210e-05 <RAD/S>
,  -3.682750220260e-04 <RAD/S>
,  -1.543913646210e-04 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
(   49118869.452 <KM>
,   -6428890.231 <KM>
,    -319061.962 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
(   2.806568 <KM/S>
,   7.298245 <KM/S>
,   0.847287 <KM/S>
)
TARGET_SUN_POSITION_VECTOR        =
(   56669336.529 <KM>
,  129046247.358 <KM>
,   55945638.589 <KM>
)
TARGET_SUN_VELOCITY_VECTOR        =
( -27.144124 <KM/S>
,  10.326189 <KM/S>
,   4.477789 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR      =
(          0.000 <KM>
,          0.000 <KM>
,          0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR      =
(   0.000000 <KM/S>
,   0.000000 <KM/S>
```

```
,    0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR            =
(    7550467.077 <KM>
,  135475137.589 <KM>
,   56264700.551 <KM>
)
SC_EARTH_POSITION_VECTOR          =
(  -49109933.310 <KM>
,    6425187.955 <KM>
,     318717.944 <KM>
)
SUB_SPACECRAFT_LONGITUDE     =    41.0630015 <DEG>
SUB_SPACECRAFT_LATITUDE      =     -0.3225872 <DEG>
SUB_SOLAR_LONGITUDE          =   114.8285460 <DEG>
SUB_SOLAR_LATITUDE           =     21.6690802 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME       = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0265306168_1001003_004_RR.FIT"
PROCESSING_HISTORY_TEXT      = "
FILEVERN=            1.1000000 / Version number of file format
PGMNAME = 'DICAL   '           / Program name that produced this file
PGMVERN =            5.0000000 / Version number of the above program
DATAQUAL=                 -999 / Data quality
TMPVLTUP=                    F / Physical temps and voltages updated(T/F)
TMPVLTV = '        '           / Valid date of physical temps, volts used
SMOBENT =           -1.0000000 / Smoothed over time version of OPTBENT[K]
CMPRESSN=                    F / Decompression performed (T/F)
LUTTABLE= '        '           / Lossy lookup table/algorithm applied
CMPRMETH=                 -999 / Decompress method. 1
SATPIX  =                    T / Saturated pixels flagged (T/F)
SMSATVL =                 8000 / DN value where some pixels are saturated
MSTSATVL=                11000 / DN value where most pixels are saturated
ADCSATVL=                16383 / DN value where the ADC encoder is
saturated
BITCORR =                    F / Uneven bit weighting corrected (T/F)
BITLUT  = '        '           / Bit weighting lookup table used
DARKCORR=                    T / Dark subtraction (T/F)
DARKALG = 'MODEL   '           / Algorithm used to create dark
DARKFN  = 'HRIIR_050620_1_2.FIT' / File name for frame/model used
BIASFN  = '        '           / Filename of bias frame used
XTALK   =                    T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIIR_050112_1_2.FIT' / Filename of crosstalk gains used
GAINCORR=                    F / Quadrant Gain correction performed (T/F)
GAINFN  = '        '           / Filename of gain values used
FLATCORR=                    F / Flat fielded
FLATFILE= '        '           / Name of flat field applied
BPIXFL  =                    T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIIR_080528_1_2_999.FIT' / Name of bad pixel map applied
CLEAN   =                    F / Cleaned/fill small gaps (T/F)
CLEANV  =                 -999 / Max filled gap size; -999999
CLNBAD  =                    F / Bad pixels cleaned
CLNMISS =                    F / Missing data cleaned
DESPIKE =                    F / Despiking applied (T/F)
```

```
DESPIKET=                 -999 / Despiking threshold used (sigma)
DESPIKEI=                 -999 / Number of iterations of despiking
DESPIKEB=                 -999 / Boxsize for despiking
DESPIKEM= '        '           / Metric used for despiking.Mean or Median
DENOISE =                    F / Denoising applied (T/F)
DENOISEV= '        '           / Denoise parameter applied
DECON   =                    F / Deconvolution performed (T/F)
DECONPSF= '        '           / Deconvolution psf used
DECONALG= '        '           / Deconvolution algorithm used
DECONV  = '        '           / Deconvolution algorithm-specific param
LINEARIZ=                    T / Linearization applied (T/F)
LINAC0  = 'HRIIR_050115_3_2.FIT' / Quad A additive constant to linearize
LINAC1  = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x term
LINAC2  = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x-squared term
LINAC3  = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x-cubed term
LINAC4  =         -999.0000000 / Quad A coefficient for x-4th term
LINBC0  = 'HRIIR_050115_3_2.FIT' / Quad B additive constant to linearize
LINBC1  = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x term
LINBC2  = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x-squared term
LINBC3  = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x-cubed term
LINBC4  =         -999.0000000 / Quad B coefficient for x-4th term
MDARKVER=            2.0000000 / Master dark frame version
DRKPMODE=                    2 / Mode of the previous set taken
DARKISG =          636.6120000 / Inter-sequence gap [msec]
DARKA0  =        3.0060000E+10 / Dark level temp coef A_0
DARKA1  =        -3384.4000000 / Dark level temp coef A_1
DARKB0  =     65630000.0000000 / Dark level temp coef B_0
DARKB1  =        -2002.0000000 / Dark level temp coef B_1
DARKC0  =            0.0583000 / Dark level temp coef C_0
DRKTMSCL=            1.0000000 / Dark scaling factor for time dependency
DARKPLAT=                    T / Dark plateau reached
DARKMSCL=         -999.0000000 / Manually derived scaling factor
CALCORR =                    T / Calibration Applied (T/F)
CALCONST=         -999.0000000 / Calibration Constant Applied
CALNUMB0=                    0 / Number of ZERO calibration factors found
CALMAP1 = 'HRIIR_050112_9_2_999.FIT' / Calib constant map interped (1)
CALMAP2 = 'HRIIR_050112_9_2_000.FIT' / Calib constant map interped (2)
SPECMAP1= '        '           / Spectral map interpolated over (1)
SPECMAP2= '        '           / Spectral map interpolated over (2)
HLUTFN  = '        '           / H lambda lookup table used
"

/***** IMAGE STATISTICS *****/
EPOXI:BAD_PIXEL_COUNT               = 5680
EPOXI:MISSING_PIXEL_COUNT           = 50
EPOXI:DESPIKED_PIXEL_COUNT          = 0
EPOXI:INTERPOLATED_PIXEL_COUNT      = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 16
EPOXI:SATURATED_PIXEL_COUNT         = 10
EPOXI:ADC_SATURATED_PIXEL_COUNT     = 0
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT  = 0

OBJECT     = HEADER
  BYTES              = 48960
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 17
```

```
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 512
  LINES            = 128
  SAMPLE_BITS      = 32
  SAMPLE_TYPE      = "IEEE_REAL"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT             = "W/(m**2*sr*um)"
  EPOXI:MINIMUM            = -1.70204000000e+01
  EPOXI:MAXIMUM            = 1.58491000000e+02
  EPOXI:MEDIAN             = -6.84000000000e-03
  EPOXI:STANDARD_DEVIATION = 3.06571000000e+00
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT             = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES     = 512
  LINES            = 128
  SAMPLE_BITS      = 8
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

OBJECT     = EXT_WAVELENGTH_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
```

```
  RECORDS             = 1
  DESCRIPTION         = "This extension provides the spectral
   wavelength for each pixel in the primary image array."
END_OBJECT = EXT_WAVELENGTH_HEADER

OBJECT              = EXT_WAVELENGTH_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 32
  SAMPLE_TYPE       = "IEEE_REAL"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION    = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT              = "MICROMETER"
END_OBJECT          = EXT_WAVELENGTH_IMAGE

OBJECT     = EXT_SPEC_BANDWIDTH_HEADER
  BYTES               = 2880
  HEADER_TYPE         = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS             = 1
  DESCRIPTION         = "This extension provides the spectral
   bandwidth for each pixel in the primary image array."
END_OBJECT = EXT_SPEC_BANDWIDTH_HEADER

OBJECT              = EXT_SPEC_BANDWIDTH_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 32
  SAMPLE_TYPE       = "IEEE_REAL"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION    = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT              = "MICROMETER"
END_OBJECT          = EXT_SPEC_BANDWIDTH_IMAGE

OBJECT     = EXT_SNR_HEADER
  BYTES               = 2880
  HEADER_TYPE         = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS             = 1
  DESCRIPTION         = "This extension is the signal-to-noise ratio
   for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT              = EXT_SNR_IMAGE
  LINE_SAMPLES      = 512
  LINES             = 128
  SAMPLE_BITS       = 32
  SAMPLE_TYPE       = "IEEE_REAL"
  AXIS_ORDER_TYPE   = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION    = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_SNR_IMAGE

END
```

4.4.4 Level 3/4 (Calibrated) HRIV/MRI Science Data Product

The calibrated science data products for the HRIV and MRI instruments have self-consistent formats. Therefore, only an example of a PDS label for reversible, calibrated HRIV FITS science image in units of radiance (RADREV, not cleaned) is provided below. Labels for RAD (radiance units, cleaned) science images have the same format. As noted in section 3.1.4, the RADREV and RAD products for HRIV and MRI include a multiplicative factor for converting from units of radiance to unitless I-over-F: EPOXI:DATA_TO_IOVERF_MULTIPLIER in the PDS labels or MULT2IOF in the FITS headers.

Labels for reduced HRIV and MRI navigation images are identical to the example below, except several keywords in the FITS header do not exist because the flight software did not include the information in the minimal image headers.

```
PDS_VERSION_ID   = PDS3
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 842

^HEADER = ("HV08060416_1000001_001_RR.FIT",1)
^IMAGE = ("HV08060416_1000001_001_RR.FIT",19)
^EXT_QUALITY_FLAGS_HEADER = ("HV08060416_1000001_001_RR.FIT",384)
^EXT_QUALITY_FLAGS_IMAGE = ("HV08060416_1000001_001_RR.FIT",385)
^EXT_SNR_HEADER = ("HV08060416_1000001_001_RR.FIT",477)
^EXT_SNR_IMAGE = ("HV08060416_1000001_001_RR.FIT",478)

DATA_SET_ID          = "DIF-E-HRIV-3/4-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID        = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HV08060416_1000001_001_RR_FIT"
PRODUCT_CREATION_TIME = 2009-03-12T00:44:08
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2008-06-04T16:57:24.642
EPOXI:IMAGE_MID_TIME = 2008-06-04T16:57:24.649
STOP_TIME            = 2008-06-04T16:57:24.656
START_JULIAN_DATE_VALUE = 2454622.2065352
MID_JULIAN_DATE_VALUE   = 2454622.2065353
STOP_JULIAN_DATE_VALUE  = 2454622.2065354
SPACECRAFT_CLOCK_START_COUNT      = "1/0265869939.131"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0265869939.132"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0265869939.134"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2008-06-04T17:00:12.888

/***** OBSERVATION INFORMATION *****/
```

```
MISSION_PHASE_NAME           = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE  = "EARTHOBS"
EPOXI:OBSERVATION_DESC       = "HRIV RADIOMETRY 1A"
EPOXI:POINTING_DESC          = "TO EARTH"
TARGET_NAME                  = "EARTH"
INSTRUMENT_MODE_ID           = 2
EPOXI:INSTRUMENT_MODE_NAME   = "SF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "1000001"
EPOXI:IMAGE_NUMBER     = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 1
FILTER_NUMBER          = 2
FILTER_NAME            = "BLUE"
CENTER_FILTER_WAVELENGTH    = 450 <NM>
EPOXI:INTEGRATION_DURATION  = 13.5000000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 303.9532000 <K>
, 303.9899680 <K>
, 296.2441760 <K>
, 302.0412640 <K>
, 283.4121440 <K>
, 163.2127061 <K>
, 137.3380562 <K>
, 137.1009052 <K>
, 131.8059846 <K>
, 135.7561008 <K>
, 84.1435000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2049545 <V>
, 1.2159419 <V>
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1106113 <V>
, 5.1050485 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0104812 <V>
, -9.2021797 <V>
, 0.2458221 <V>
```

```
, 0.7423583 <V>
, 3.4060428 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE   = 100893.168 <M/PIXEL>
VERTICAL_PIXEL_SCALE     = 100893.168 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE                         = "
  Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
  system used to specify observational geometry.  Geometric parameters are
  based on the best available SPICE data at the time of product creation.
  Refer to the EPOXI SPICE archive for the most current observational
  geometry.  The observation midpoint was used to derive the geometry.
  All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG       = "OK"
EPOXI:GEOMETRY_TYPE               = "RECONSTRUCTED"
SPICE_FILE_NAME    = ( "NAIF0009.TLS",
                       "PCK00008.TPC",
                       "DIF_SCLKSCET.00035.TSC",
                       "DI_V17.TF",
                       "DIF_HRI_V10.TI",
                       "DIF_MRI_V10.TI",
                       "DIF_SC_050112_050809.BC",
                       "DIF_SC_050225_HIGHRATE.BC",
                       "DIF_SC_050704_HIGHRATE.BC",
                       "DIF_SC_2008_06_04.BC",
                       "JUP164_20YEAR.BSP",
                       "SPK_OD221_FULL.BSP" )
RIGHT_ASCENSION                   = 177.489792500 <DEG>
DECLINATION                       =  -0.215176100 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE       = 113.1337 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE =  89.7128 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = 180.0005 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 113.1357 <DEG>
SOLAR_ELONGATION                  =  84.1632 <DEG>
```

```
PHASE_ANGLE                        =  76.533 <DEG>
TARGET_CENTER_DISTANCE             =   50446583.8460 <KM>
TARGET_HELIOCENTRIC_DISTANCE       =  151789311.363 <KM>
TARGET_GEOCENTRIC_DISTANCE         =          0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE     =  148385381.127 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE       =   50436998.201 <KM>
QUATERNION_DESC                     = "QUATERNION_DESC.ASC"
QUATERNION                          =
(  0.688178800000
,  0.126812100000
, -0.696991000000
, -0.156627400000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
(  -6.193104793090e-07 <RAD/S>
,   5.662622783320e-07 <RAD/S>
,  -2.666095006670e-06 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
(   50397729.649 <KM>
,   -2211519.755 <KM>
,     189336.499 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
(   1.724195 <KM/S>
,   7.629346 <KM/S>
,   0.946928 <KM/S>
)
TARGET_SUN_POSITION_VECTOR        =
(   41049886.647 <KM>
,  134075548.433 <KM>
,   58126148.701 <KM>
)
TARGET_SUN_VELOCITY_VECTOR        =
( -28.206501 <KM/S>
,   7.494698 <KM/S>
,   3.248512 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR      =
(          0.000 <KM>
,          0.000 <KM>
,          0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR      =
(   0.000000 <KM/S>
,   0.000000 <KM/S>
,   0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR            =
(   -9347843.002 <KM>
,  136287068.188 <KM>
,   57936812.202 <KM>
)
SC_EARTH_POSITION_VECTOR          =
(  -50388265.569 <KM>
,    2208512.122 <KM>
,    -189617.362 <KM>
```

```
)
SUB_SPACECRAFT_LONGITUDE     =   210.5053179 <DEG>
SUB_SPACECRAFT_LATITUDE      =      0.2619271 <DEG>
SUB_SOLAR_LONGITUDE          =   286.0135359 <DEG>
SUB_SOLAR_LATITUDE           =     22.5295803 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME       = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0265869939_1000001_001_RR.FIT"
EPOXI:DATA_TO_IOVERF_MULTIPLIER   = 0.0017237002
EPOXI:DATA_TO_RADIANCE_MULTIPLIER = 1.0
EPOXI:DATA_TO_DN_MULTIPLIER       = 14.030347
PROCESSING_HISTORY_TEXT      = "
FILEVERN=            1.1000000 / Version number of file format
PGMNAME = 'DICAL   '           / Program name that produced this file
PGMVERN =            5.0000000 / Version number of the above program
DATAQUAL=                 -999 / Data quality (1
TMPVLTUP=                    F / Physical temps, voltages updated (T/F)
TMPVLTV = '        '           / Valid date of physical temps, volts used
SMOBENT =           -1.0000000 / Smoothed over time version of OPTBENT[K]
CMPRESSN=                    F / Decompression performed (T/F)
LUTTABLE= '        '           / Lossy lookup table/algorithm applied
CMPRMETH=                 -999 / Decompress method. 1
SATPIX  =                    T / Saturated pixels flagged (T/F)
SMSATVL =                11000 / DN value where some pixels are saturated
MSTSATVL=                15000 / DN value where most pixels are saturated
ADCSATVL=                16383 / DN value where ADC encoder is saturated
BITCORR =                    F / Uneven bit weighting corrected (T/F)
BITLUT  = '        '           / Bit weighting lookup table used
DARKCORR=                    T / Dark subtration (T/F)
DARKALG = 'MODEL   '           / Algorithm used to create dark
DARKFN  = 'HRIVIS_020601_2_2.FIT' / File name for frame/model used
BIASFN  = 'SERIAL OVERCLOCK'   / Filename of bias frame used
XTALK   =                    T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIVIS_071004_1_2.FIT' / Filename of crosstalk gains used
GAINCORR=                    F / Quadrant Gain correction performed (T/F)
GAINFN  = '        '           / Filename of gain values used
FLATCORR=                    T / Flat fielded
FLATFILE= 'HRIVIS_050701_1_2_2.FIT' / Name of flat field applied
BPIXFL  =                    T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIVIS_020601_2_2_999.FIT' / Name of bad pixel map applied
CLEAN   =                    F / Cleaned/fill small gaps (T/F)
CLEANV  =                 -999 / Max filled gap size; -999999
CLNBAD  =                    F / Bad pixels cleaned
CLNMISS =                    F / Missing data cleaned
DESPIKE =                    F / Despiking applied (T/F)
DESPIKET=                 -999 / Despiking threshold used (sigma)
DESPIKEI=                 -999 / Number of iterations of despiking
DESPIKEB=                 -999 / Boxsize for despiking
DESPIKEM= '        '           / Metric used for despiking.Mean or Median
DENOISE =                    F / Denoising applied (T/F)
DENOISEV= '        '           / Denoise parameter applied
DECON   =                    F / Deconvolution performed (T/F)
DECONPSF= '        '           / Deconvolution psf used
DECONALG= '        '           / Deconvolution algorithm used
```

```
DECONV  = '        '            / Deconvolution algorithm-specific param
SMEAR   =                     T / Frame-transfer smear removed (T/F)
SMEARV  = 'POC ROWS'            / Smear removal algorithm applied
RADCAL  =                     T / Radiance calibration applied (T/F)
RADCALV =             0.0009622 / Rad cal const used[W/(m^2 sr um)/(DN/s)]
RADCALW =                452.48 / Radiance calib - wavelength used [nm]
IOFCAL  =                     F / I/F calibration applied (T/F)
IOFCALV =          1876.3752000 / I/F cal const used[W/(m^2 sr um) @ 1 AU]
IOFCALW =                454.19 / I/F calib - wavelength used [nm]
IOFCALD =             1.0146489 / I/F calib - Distance used [AU]
MULT2RAD=                     1 / Multiplier to convert data to Radiance
MULT2IOF=          0.0017237002 / Multiplier to convert data to I/F
MULT2DN =             14.030347 / Multiplier to convert data to DN
GEOMCAL =                     F / Geometric calibration performed (T/F)
GEOMFILE= '        '            / File used for geometric calibration
"

/***** IMAGE STATISTICS *****/
EPOXI:BAD_PIXEL_COUNT               = 1024
EPOXI:MISSING_PIXEL_COUNT           = 50
EPOXI:DESPIKED_PIXEL_COUNT          = 0
EPOXI:INTERPOLATED_PIXEL_COUNT      = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 971
EPOXI:SATURATED_PIXEL_COUNT         = 948
EPOXI:ADC_SATURATED_PIXEL_COUNT     = 900
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT  = 0

OBJECT     = HEADER
  BYTES              = 51840
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 18
  DESCRIPTION        = "FITS format defined in
     NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT             = IMAGE
  LINE_SAMPLES     = 512
  LINES            = 512
  SAMPLE_BITS      = 32
  SAMPLE_TYPE      = "IEEE_REAL"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT             = "W/(m**2*sr*um)"
  EPOXI:MINIMUM            = -7.44281000000e-01
  EPOXI:MAXIMUM            = 3.11041000000e+02
  EPOXI:MEDIAN             = 4.86289000000e-02
  EPOXI:STANDARD_DEVIATION = 1.90605000000e+01
END_OBJECT         = IMAGE

OBJECT     = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
```

```
   each pixel in the primary image array.  Each of the one-byte pixels
   in this map is composed of eight bits.  Each bit represents a specific
   characteristic about the corresponding pixel in the primary image
   array.  For a raw image, only the bit for a missing data value is set
   (bit 1 below).  The remaining 7 bits apply only to a calibrated image
   and are thus set to zero for a raw image.  The bits are described below
   and are listed from the least-significant (0) to most-significant (7):
     0 = Bad
     1 = Data for this pixel was not received from the spacecraft or
         this pixel is one of the image header bytes.
     2 = Despiked
     3 = Interpolated
     4 = Partially saturated
     5 = Mostly saturated
     6 = ADC saturated
     7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT             = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES     = 512
  LINES            = 512
  SAMPLE_BITS      = 8
  SAMPLE_TYPE      = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

OBJECT     = EXT_SNR_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension is the signal-to-noise ratio
   for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT             = EXT_SNR_IMAGE
  LINE_SAMPLES     = 512
  LINES            = 512
  SAMPLE_BITS      = 32
  SAMPLE_TYPE      = "IEEE_REAL"
  AXIS_ORDER_TYPE  = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION   = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_SNR_IMAGE

END
```

4.5 PDS Object and Keyword Definitions

This section provides definitions for the objects and keywords found in the PDS labels for raw and calibrated FITS science data products. Definitions are ordered following the label examples provided in the previous sections. (FITS keyword definitions are provided in 'EPOXI Data Archive: FITS Keyword Descriptions for the Primary Image Header' by Carcich, 2009 [15] located in the Deep Impact and EPOXI documentation set.)

All time- and geometry-related keyword values are based on the time at the spacecraft, except EARTH_OBSERVER_MID_TIME that provides the UTC of the image mid-time for an observer on Earth. All values for geometry-related keywords were calculated for the mid-point of an image at the spacecraft ***except for "target-to-sun" and "earth -to-target" keywords***. The values for target-to-sun were calculated for the time (with respect to image mid-time) when the light arrived at the target while the values for earth-to-target were calculated for the time when the light left the target.

PDS Keyword or Object	Definition
PDS_VERSION_ID	Represents the version number of the PDS standards documents that is valid when a data product label is created. PDS3 is used for Deep Impact data products.
RECORD_TYPE	Indicates the record format of a file. The value FIXED_LENGTH is for FITS data products. The physical record length (RECORD_BYTES) corresponds directly to the logical record length of the data objects (that is, one physical record for each image line, or one physical record for each row of a table).
RECORD_BYTES	Indicates the number of bytes in a physical file record, including record terminators and separators. For FITS data products, the value is 2880.
FILE_RECORDS	Indicates the number of physical file records, including both label records and data records. Note: In the PDS, the use of the file_records keyword along with other file-related data elements is fully described in the PDS Standards Reference.

/ OBJECT POINTERS **/**	
^HEADER	This object identifies and defines the attributes of the FITS header for the primary image array (see ^IMAGE below). The use of bytes within the header object refers to the number of bytes for the entire header, not a single record,
^IMAGE	This object defines the primary, two-dimensional FITS image array of sample values. Images are composed of LINES and SAMPLES.
^EXT_QUALITY_FLAGS_HEADER	This object identifies and defines the attributes of the header for the quality map, an image extension in all raw and reduced FITS files.
^EXT_QUALITY_FLAGS_IMAGE	This object provides the quality map, an image extension in all raw and reduced FITS files. The map or array is the same size as the primary image and provides information about the quality of each pixel in the primary image array.
^EXT_WAVELENGTH_HEADER	Used only for calibrated, HRII images. This object identifies and defines the attributes of the header for the pixel-by-pixel spectral wavelength map.
^EXT_WAVELENGTH_IMAGE	Used only for calibrated HRII images. This object provides the pixel-by-pixel spectral wavelength map. The array provides the wavelength for each pixel in the primary image array.
^EXT_SPEC_BANDWIDTH_HEADER	Used only for calibrated HRII images. This object identifies and defines the attributes of the pixel-by-pixel spectral bandwidth map.
^EXT_ SPEC_BANDWIDTH _IMAGE	Used only for calibrated HRII images. The object provides the pixel-by-pixel spectral bandwidth map. The array provides the spectral bandwidth for each pixel in the primary image array.
^EXT_SNR_HEADER	Used only for calibrated images. This object identifies and defines the attributes of the pixel-by-pixel, signal-to-noise ratio (SNR) map.
^EXT_SNR_IMAGE	Used only for calibrated images. The object provides the pixel-by-pixel SNR map. The array provides a signal-to-noise ratio for each pixel in the primary image array.

/** DATA SET INFORMATION **/	
DATA_SET_ID	Provides a unique alphanumeric identifier for a data set or a data product. The DATA_SET_ID is constructed according to instructions outlined in the PDS Standards Reference. Source: Hardcoded.
MISSION_NAME	Provides the name of the mission: EPOXI. Source: FITS header keyword MISSION.
INSTRUMENT_HOST_NAME	Provides the full name of the host on which an instrument is based. For EPOXI, there is only one value: Deep Impact Flyby Spacecraft. Source: Derived from FITS header keyword OBSERVAT.
INSTRUMENT_HOST_ID	Provides a unique identifier for the host where an instrument is located. For EPOXI, there is only one value: DIF = DI flyby spacecraft. Source: Derived from FITS header keyword OBSERVAT.
INSTRUMENT_NAME	Provides the full name of an instrument based on the value for INSTRUMENT_ID: - Deep Impact High-Resolution Instrument - Infrared Spectrometer - Deep Impact High-Resolution Instrument - Visible CCD - Deep Impact Medium-Resolution Instrument - Visible CCD Source: FITS header keyword INSTRUME converted to one of the above values.
INSTRUMENT_ID	Provides an abbreviated name or acronym that identifies an instrument. The possible values are HRII, HRIV, and MRI. Source: FITS header keyword INSTRUME converted from HRIIR, HRIVIS, or MRIVIS to HRII, HRIV, or MRI, respectively.

/ PRODUCT INFORMATION **/**	
PRODUCT_ID	Represents a permanent, unique identifier assigned to a data product by its producer. Note: In the PDS, the value assigned to PRODUCT_ID must be unique within its data set. Source: FITS file name with the period converted to an underscore.
PRODUCT_CREATION_TIME	Defines the UTC system format time when a product label was created. Formation rule: YYYY-MM-DDThh:mm:ss. Source: FITS header keyword DATE.
PRODUCT_TYPE	Provides the type or category of a product within a data set. The possible values are: RAW = Raw data record RADIANCE_REVERSIBLE = Reversibly calibrated radiance data record RADIANCE_CLEANED = Irreversibly cleaned, calibrated radiance data record Source: Hardcode based on the level of data reduction.

/** **TIME INFORMATION** **/	
START_TIME	Provides the date and time at the spacecraft for the beginning of an observation in UTC system format. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSDATE.
EPOXI: IMAGE_MID_TIME	Provides the UTC date and time at the spacecraft of the midpoint between the start and end times. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSMIDDT.
STOP_TIME	Provides the date and time at the spacecraft or the end of an observation in UTC system format. Formation rule: Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSENDDT.
START_JULIAN_DATE_VALUE	Provides the full Julian date corresponding to the UTC START_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn Source: FITS header keyword OBSJD.
MID_JULIAN_DATE_VALUE	Provides the full Julian date corresponding to the UTC EPOXI:IMAGE_MID_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn Source: FITS header keyword OBSMIDJD.
STOP_JULIAN_DATE_VALUE	Provides the full Julian date corresponding to the UTC STOP_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn Source: FITS header keyword OBENDJD.
SPACECRAFT_CLOCK_START_COUNT	Provides the value of the spacecraft clock at the beginning of an observation. Formulation rule: p/ssssssssss.fff where p is clock partition (1 for cruise and encounter phases), ssssssssss is the clock seconds count, fff is the sub-seconds tick (1 tick is 1/256th of a second). Source: FITS header keyword SCSTART.
EPOXI: SPACECRAFT_CLOCK_MID_COUNT	Provides the value of the spacecraft clock at the midpoint of an observation. Formulation rule: p/ssssssssss.fff where p is clock partition (1 for cruise and encounter phases), ssssssssss is the clock seconds count, fff is the sub-seconds tick (1 tick is 1/256th of a second). Source: FITS header keyword ADCTIME.
SPACECRAFT_CLOCK_STOP_COUNT	Provides the value of the spacecraft clock at the end of an observation. Formulation rule: p/ssssssssss.fff where p is clock partition (1 for cruise and encounter phases), ssssssssss is the clock seconds count, fff is the sub-seconds tick (1 tick is 1/256th of a second). Source: FITS header keyword SCSTOP.
EPOXI:EARTH_OBSERVER_MID_TIME	Provides the calendar UTC time when light from the target, which left the target at the same time as light reached the Deep Impact spacecraft at the UTC mid-point of the observation (IMAGE_MID_TIME), reaches the center of Earth. Formation rule: YYYY-MM-DDThh:mm:ss[.fff]. Source: FITS header keyword EAROBSDT.

/** OBSERVATION INFORMATION **/	
MISSION_PHASE_NAME	Identifies the mission phase: CRUISE 1 EPOCH CRUISE 2 DIXI Source: Hardcoded.
EPOXI: MISSION_ACTIVITY_TYPE	Identifies the mission activity such as "Instrument Checkout". Source: FITS header keyword KPKIMNTL.
EPOXI:OBSERVATION_DESC	Provides a description of the observation or image such as "Radiometry". Source: FITS header keyword KPKICMMT.
EPOXI:POINTING_DESC	Provides the planned instrument pointing as described in an imaging sequence. Source: FITS header keyword KPKPCMMT.
TARGET_NAME	Identifies the intended mission target, such as "CALIBRATION", "GJ 436", or "103P/HARTLEY 2 (1986 E2)". For raw data, TARGET_DESC provides the name of a "CALIBRATION" target. Source: Derived from FITS header keyword OBJECT.
TARGET_DESC	Used only for raw data, identifies a specific calibration target, such as "CANOPUS" or "DARK". For mission targets, this keyword is set to the value of TARGET_NAME. This keyword allows the user to more easily search for raw calibration data. Source: FITS header keyword OBJECT.
INSTRUMENT_MODE_ID	Provides an instrument-dependent designation of operating mode. For the HRII instrument, valid modes are 1-7. For the HRIV and MRI instruments, the valid modes are 1-9. Source: FITS header keyword IMGH030.
EPOXI:INSTRUMENT_MODE_NAME	Provides the common name used by the mission for INSTRUMENT_MODE_ID. Source: FITS header keyword IMGMODEN.
EPOXI: COMPRESSED_IMAGE_VALUE	Identifies a compressed or decompressed image: UNCOMPRESSED = Image is not compressed COMPRESSED = Raw image is compressed as received from the spacecraft DECOMPRESSED = Reduced image is decompressed; all raw, compressed images are decompressed at the beginning of the calibration pipeline Source: FITS header keyword COMPRESS.
COMPRESSOR_ID	Identifies the look-up table (compressor number) used to compress an image onboard the spacecraft and to decompress an image the calibration. Valid values are 0-3. Images that were never compressed in-flight this keyword set to "N/A". Source: If the file is compressed (if FNCMPRSS = "C" in FITS header), then set to FITS header keyword IMGH0001.

EPOXI:OBSERVATION_ID	Identifies a set of images, also known as a sequence, taken by the same command using a 7-digit value. Also known as exposure ID. It is used with IMAGE_NUMBER. For example, exposure ID 9000000 and image number 2 identifies the second image taken for the commanded exposure ID. Source: FITS header keyword EXPID.
EPOXI:IMAGE_NUMBER	A three-digit value that identifies the order of an image within an exposure ID (see OBSERVATION_ID). Values are 001 through 999. One HRII OBSERVATION_ID typically consists of several, thus IMAGE_NUMBER is incremented for each frame in the sequence. Source: FITS header keyword IMGH026.
EPOXI: COMMANDED_IMAGE_COUNT	Provides to total number of images commanded for a specific observation (exposure) ID. See OBSERVATION_ID and IMAGE_NUMBER. Source: FITS header keyword IMGH027.
FILTER_NUMBER	Provides the number, an integer, of the filter used for this observation. The Hall Sensor location was sourced because it was the best indicator of the actual filter used for a given observation. A value of UNK indicates the filter could not be determined (is unknown). The HRII instrument did not have filter wheels, so this keyword is set to N/A (not applicable). HRIV | # | Name | Center λ (nm) | Width (nm) | | -- | --------------- | ---------- | ------------------------------ | | 1 | CLEAR1 | 650 | >700 | | 2 | BLUE | 450 | 100 | | 3 | GREEN | 550 | 100 | | 4 | VIOLET | 350 | 100 (cut-on is ~340 nm) | | 5 | IR | 950 | 100 (longpass) | | 6 | CLEAR6 | 650 | >700 | | 7 | RED | 750 | 100 | | 8 | NIR | 850 | 100 | | 9 | ORANGE | 950 | 100 | MRI | # | Name | Center λ (nm) | Width (nm) | | -- | ---------------------- | ----------- | ------------------------- | | 1 | CLEAR1 | 650 | >700 | | 2 | C2 | 514 | 11.8 | | 3 | GREEN_CONT | 526 | 5.6 | | 4 | RED | 750 | 100 | | 5 | IR | 950 | 100 (longpass) | | 6 | CLEAR6 | 650 | >700 | | 7 | CN | 387 | 6.2 | | 8 | VIOLET_CONT | 345 | 6.8 | | 9 | OH | 309 | 6.2 | Source: Decode FITS header keyword FILTER.

FILTER_NAME	Provides the name of the filter used for this observation. The Hall Sensor location was used because it was the best indicator of the actual filter used. A value of "UNK" indicates the filter could not be determined. This keyword is not applicable for HRII and is set to "N/A". Source: FITS header keyword FILTER.
CENTER_FILTER_WAVELENGTH	Provides the wavelength for the center of a filter bandpass in microns. A value of "UNK" indicates the filter could not be determined. This keyword is not applicable for HRII and is set to "N/A". Source: FITS header keyword FILTERCW.
EPOXI: INTEGRATION_DURATION	Provides the total integration time for the image in units of milliseconds. Integration duration is calculated as follows: For HRII, all modes: integration_duration = minimum_exposure_duration + commanded_exposure_duration For HRIV and MRI shuttered modes (1, 2, 3, 5, and 9): integration_duration = minimum_exposure_duration + commanded_exposure_duration For HRIV and MRI unshuttered modes (4, 6, 7, and 8): integration_duration = minimum_exposure_duration + commanded_exposure_duration + interframe_delay_duration + (0.5 ms if interframe_delay_duration > 0) Minimum exposure times are given in Tables 1 and 2. Source: FITS header keyword INTTIME.
EPOXI:SPACECRAFT_PROCESSOR_ID	Identifies one of two processor units onboard the DI spacecraft the processed and stored the image file. Source: FITS header keyword SCUPROCU.
INSTRUMENT_TEMPERATURE	Provides the temperature, in degrees Kelvin, of an instrument or some part of an instrument. Multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_TEMPERATURE list with a corresponding item in the INSTRUMENT_TEMPERATURE_POINT sequence of values. The temperature values were extracted from the original image headers that were generated onboard the spacecraft. Values from the nearest thermal telemetry were put in the image headers. For HRII, the best temperatures are in the thermal telemetry data set for the flyby spacecraft, DIF-CAL-HRII/HRIV/MRI-6-TEMPS-V1.0 A value of "N/A" means the measurement was not applicable. A value of "UNK" indicated the measurement could not be determined or did not exist. Source: FITS header keywords ICT590T, CCD590T, IR590T, LVPS590T, CCDPRET, CCDT, OPTBENT, PRIMIRT, SECMIRT, COVERT, and IRFPAT.

INSTRUMENT_TEMPERATURE_POINT	Identifies the measurement point or location on an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_TEMPERATURE to more fully describe either single or multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_TEMPERATURE list with a corresponding item in the INSTRUMENT_TEMPERATURE_POINT sequence of values. Values used for HRII and HRIV are: INSTRUMENT CONTROLLER PROCESSING BOARD CCD SIGNAL PROCESSING BOARD IR SIGNAL PROCESSING BOARD LVPS SIGNAL PROCESSING BOARD CCD PREAMP BOX CCD ON-CHIP SENSOR PRISMS PRIMARY MIRROR SECONDARY MIRROR SPECTRAL IMAGING MODULE COVER IR FPA ON-CHIP SENSOR Values used for MRI are: INSTRUMENT CONTROLLER PROCESSING BOARD CCD SIGNAL PROCESSING BOARD IR SIGNAL PROCESSING BOARD LVPS SIGNAL PROCESSING BOARD CCD PREAMP BOX CCD ON-CHIP SENSOR OPTICAL BENCH PRIMARY MIRROR SECONDARY MIRROR STRUCTURE COVER IR FPA ON-CHIP SENSOR Source: Hardcoded.

INSTRUMENT_VOLTAGE	Provides the voltage, in volts, of an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_VOLTAGE_POINT to more fully describe either single or multiple voltages at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each voltage measurement in the INSTRUMENT_VOLTAGE list with a corresponding item in the INSTRUMENT_VOLTAGE_POINT sequence of values. A value of "N/A" means the measurement was not applicable. A value of "UNK" indicated the measurement could not be determined or did not exist. Source: FITS header keywords CCDOFSAV, CCDOFSBV, CCDOFSCV, CCDOFSDV, CCDOUTAV, CCDOUTBV, CCDOUTCV, CCDOUTDC, CCDSERPV, CCDSERNV, CCDPARPV, CCDPARNV, IRRESETV, IRSUBSTV, IRBIASGV, and ALLAMPV.
INSTRUMENT_VOLTAGE_POINT	Identifies the measurement point or location on an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_VOLTAGE to more fully describe either single or multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_VOLTAGE list with a corresponding item in the INSTRUMENT_VOLTAGE_POINT sequence of values. The following values are used for all instruments: CCD OFFSET FROM ADC REF QUAD A CCD OFFSET FROM ADC REF QUAD B CCD OFFSET FROM ADC REF QUAD C CCD OFFSET FROM ADC REF QUAD D CCD OUTPUT AMP DRAIN QUAD A CCD OUTPUT AMP DRAIN QUAD B CCD OUTPUT AMP DRAIN QUAD C CCD OUTPUT AMP DRAIN QUAD D CCD SERIAL CLOCK POSITIVE CCD SERIAL CLOCK NEGATIVE CCD PARALLEL CLOCK POSITIVE CCD PARALELL CLOCK NEGATIVE IR RESET IR SUBSTRATE IR BIASGATE IR CALIB LAMP Source: Hardcoded.

/** IMAGE INFORMATION***/	
HORIZONTAL_PIXEL_SCALE	Indicates the horizontal picture scale in units of meters per pixel for the HRIV and MRI instruments. This keyword is set to "N/A" for HRII images. For non-planetary, calibration targets, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keyword PXLSCALE.
VERTICAL_PIXEL_SCALE	Indicates the vertical picture scale in units of meters per pixel for the HRII, HRIV, and MRI instruments. For non-planetary, calibration targets, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keyword PXLSCALE.
/** GEOMETRY PARAMETERS **/	
NOTE	States that the Earth Mean Equator and Vernal Equinox J2000 (EME J2000) is the inertial reference frame, unless otherwise specified. Geometric parameters are based on the best available SPICE data at the time a product was produced. The observation midpoint was used to derive the geometry, and all positions are relative to body centers. Source: Hardcoded.
EPOXI:GEOMETRY_QUALITY_FLAG	Indicates the quality of the geometry values. 'OK' indicates geometry is good. 'BAD' indicates the data should be used with caution. Source: FITS header keyword GEOMSTAT.
EPOXI:GEOMETRY_TYPE	Indicates if preliminary ('PREDICTED') or finalized ('RECONSTRUCTED') SPICE kernels were used to generate geometry values. Source: FITS header keyword GEOMQUAL.
SPICE_FILE_NAME	Provides a list of the SPICE kernels used to calculate the values for the geometry-related. The kernels are listed in the order they were loaded for processing. Source: FITS header keywords RECK0001 through RECK00nn if GEOMETRY_TYPE is 'RECONSTRUCTED' or NOMK0001 through NOMK00nn if GEOMETRY_TYPE is 'PREDICTED'.
RIGHT_ASCENSION	Provides the right ascension, in the EME J2000 reference, where the boresight was pointing, in degrees. Source: FITS header keyword BORERA for mission targets or UNK for calibration targets,
DECLINATION	Provides the declination, in the EME J2000 reference, where the boresight was pointing, in degrees. Source: FITS header keyword BOREDEC for mission targets or UNK for calibration targets.

CELESTIAL_NORTH_CLOCK_ANGLE	Specifies the direction of celestial north at the center of an image. It is measured from the 'upward' direction, clockwise to the direction toward celestial north (declination = +90 degrees), when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. The epoch of the celestial coordinate system is J2000 unless otherwise indicated. For images pointed near either pole, the value varies significantly across the image; in these cases, the element is very sensitive to the accuracy of the pointing information. Source: FITS header keyword CELESTN for mission targets or UNK for calibration targets.
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE	Specifies the direction of ecliptic north at the center of the image. It is measured from the 'upward' direction, clockwise to the direction toward ecliptic north when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. The epoch of the coordinate system is J2000 unless otherwise indicated. Source: FITS header keyword ECLN for mission targets or UNK for calibration targets.
EPOXI:SUN_DIRECTION_CLOCK_ANGLE	Specifies the direction to the Sun at the center of the image. It is measured from the 'upward' direction, clockwise to the direction of the sun as projected into the image when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. Source: FITS header keyword SOLARCLK for mission targets or UNK for calibration targets.
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE	Specifies the direction of the target body's positive rotation axis in the image plane. It is measured from the 'upward' direction, clockwise to the direction of the positive rotational pole as projected into the image plane when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. Note: In some cases, knowledge of the inertial orientation of the rotational axis improves with time. This keyword necessarily reflects the state of knowledge of the rotational axis at the time of preparing the data product as given by the POLE_DECLINATION and POLE_RIGHT_ASCENSION values in the dataset or target catalog file. Source: FITS header keyword RECPPAZ or NOMPPAZ for Earth or comet Hartley 2 frames only, otherwise use UNK.
SOLAR_ELONGATION	Provides the angle, in degrees, between the target and the Sun as viewed by the observer at the mid-point of an observation. For some cases it may be the angle between the instrument boresight and the vector from the observer to the Sun. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keyword SOLARELO.

PHASE_ANGLE	Provides the angle, in degrees, between the Sun, the target, and the observer at the mid-point of an observation. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keyword PHANGLE.
TARGET_CENTER_DISTANCE	Provides the distance between the spacecraft and the center of the target, in units of kilometers. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keyword TARSCR.

TARGET_HELIOCENTRIC_DISTANCE	Provides the distance between the target and the Sun, in units of kilometers. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keyword TARSUNR.
TARGET_GEOCENTRIC_DISTANCE	Provides the distance between the target and the Earth, in units of kilometers. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keyword EARTARR.
EPOXI:SC_HELIOCENTRIC_DISTANCE	Provides the distance between the spacecraft and the Sun, in units of kilometers. Source: FITS header keyword SCSUNR. For solar system targets, if SCSUNR is > 1.0E9 then this keyword is set to “UNK”. For targets outside the solar system, “N/A” is used. If geometry is bad, then “UNK” is used.
EPOXI:SC_GEOCENTRIC_DISTANCE	Provides the distance between the spacecraft and the Earth, in units of kilometers. For targets outside the solar system, this keyword is set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keyword SCEARR.
QUATERNION_DESC	Provides a pointer to an accompanying quaternion description file used to describe the formation rules for the quaternion and the specific rotation accomplished by application of that quaternion. This keyword is required to be used in conjunction with the QUATERNION keyword. The file to which this keyword points is to be included in the /document subdirectory of an archive product. Source: Hardcoded to ‘QUATERNION_DESC.ASC’.
QUATERNION	Provides four-component representation of a rotation matrix. This quaternion rotates vectors defined in the instrument frame into the EME J2000 reference frame. Source: FITS header keywords ADCQA, ADCQB, ADCQC, and ADCQD. If geometry could not be calculated, then use UNK.
EPOXI: SC_ROTATION_VELOCITY_VECTOR	Provides the x-, y-, z-components of the angular velocity of the spacecraft about axes of the EME J2000 reference frame. Source: FITS header keywords ADCVX, ADCVY, and ADCVZ. If geometry could not be calculated then UNK.
EPOXI: TARGET_SC_POSITION_VECTOR	Provides the (x, y, z) components of the position vector, at image mid-time, from the target to the spacecraft expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSCRX, TARSCRY, and TARSCRZ.

EPOXI: TARGET_SC_VELOCITY_VECTOR	Provides the (x, y, z) components of the velocity vector, at image mid-time, from the target to the spacecraft expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSCVX, TARSCVY, and TARSCVZ.
TARGET_SUN_POSITION_VECTOR	Provides the (x, y, z) components of the position vector, at image mid-time, from the target to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSUNRX, TARSUNRY, and TARSUNRZ.
TARGET_SUN_VELOCITY_VECTOR	Provides the (x, y, z) components of the velocity vector, at image mid-time, from the target to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords TARSUNVX, TARSUNVY, and TARSUNVZ.
EARTH_TARGET_POSITION_VECTOR	Provides the (x, y, z) components of the position vector, at image mid-time, from the Earth to the target expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords EARTARRX, EARTARRY, and EARTARRZ.
EARTH_TARGET_VELOCITY_VECTOR	Provides the (x, y, z) components of the velocity vector, at image mid-time, from the Earth to the target expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to “N/A”. If geometry was not available, the components are set to “UNK”. Source: FITS header keywords EARTARVX, EARTARVY, and EARTARVZ.

SC_SUN_POSITION_VECTOR	Defines the (x, y, z) components of the position vector, at image mid-time, from the spacecraft to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. Source: FITS header keyword SCSUNRX, SCSUNRY, and SCSUNRZ. If SCSUNR is > 1.0E9 or the geometry is bad, the components of this vector are set to "UNK".
SC_EARTH_POSITION_VECTOR	Defines the (x, y, z) components of the position vector, at image mid-time, from the spacecraft to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. Source: FITS header keywords SCEARRX, SCEARRY, and SCEARRZ. If the geometry is bad then the components of this vector are set to "UNK".
SUB_SPACECRAFT_LONGITUDE	Provides the longitude of the sub-spacecraft point, the point on a body that lies directly beneath the spacecraft. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keywords RECSCLON or NOMSCLON.
SUB_SPACECRAFT_LATITUDE	Provides the latitude of the sub-spacecraft point, the point on a body that lies directly beneath the spacecraft. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keywords RECSCLAT or NOMSCLAT.
SUB_SOLAR_LONGITUDE	Provides the longitude of the sub-solar point, the point on a body's reference surface where a line from the body center to the sun center intersects that surface. This keyword is used in conjunction with coordinate_system_type. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keywords RECSOLON or NOMSOLON.
SUB_SOLAR_LATITUDE	Provides the latitude of the sub-solar point, the point on a body's reference surface where a line from the body center to the sun center intersects that surface. This keyword is used in conjunction with coordinate_system_type. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keywords RECSOLAT or NOMSOLAT.

COORDINATE_SYSTEM_TYPE	Specifies the type of coordinate system used for the sub_spacecraft_longitude/latitude and sub_solar_longitude/latitude. Source: Hardcoded to "BODY-FIXED ROTATING" if sub_spacecraft* and sub_solar* keywords are set to numeric values.
COORDINATE_SYSTEM_NAME	Provides the full name of the coordinate system associated with coordiate_system_type, sub_spacecraft_longitude/latitude, and sub_solar_longitude/latitude keywords. Source: Hardcoded to "PLANETOCENTRIC" if sub_spacecraft* and sub_solar* keywords are set to numeric values.

/** PROCESSING HISTORY **/	
EPOXI:SDC_PIPELINE_FILE_NAME	Provides the actual filename used in the data pipeline for this data file. The EPOXI project elected to modify and shorten the filename for the PDS archive.
EPOXI:DATA_TO_IOVERF_MULTIPLIER	Provides the multiplicative (scaling) factor for converting the image data from the currently specified unit to unitless I-over-F data. A value of 1 indicates the current image is already in I-over-F units. This keyword is calculated and provided only for calibrated HRIV and MRI observations. Source: FITS header keyword MULT2IOF.
EPOXI:DATA_TO_RADIANCE_MULTIPLIER	Provides the multiplicative (scaling) factor for converting the image data from the currently specified unit to radiance data, W/(m**2*micron*sr). A value of 1 indicates the current image is already in units of radiance. This keyword is calculated and provided only for calibrated HRIV and MRI observations. Source: FITS header keyword MULT2RAD.
EPOXI:DATA_TO_DN_MULTIPLIER	Provides the multiplicative (scaling) factor for converting the image data from the currently specified unit to calibrated data numbers (before the conversion to radiance). A value of 1 indicates the current image is already in raw data counts. This keyword is calculated and provided only for calibrated HRIV and MRI observations. Source: FITS header keyword MULT2DN.
PROCESSING_HISTORY_TEXT	For a calibrated data file, lists the steps performed by the calibration process. Includes the names of the calibration files, such at the dark frame, used to reduce a data file. For raw, uncalibrated data, this keyword is set to RAW. Source: FITS header keywords for calibration steps and files applied..

/ IMAGE STATISTICS **/**	
EPOXI: BAD_PIXEL_COUNT	Provides a count of the number of known bad pixels in the image array, as identified by the calibration pipeline. Source: FITS header keyword BADPXCT.
EPOXI: MISSING_PIXEL_COUNT	Provides a count of the number of pixels that were not received from the spacecraft. Source: FITS header keyword MISSPXCT.
EPOXI: DESPIKED_PIXEL_COUNT	Provides a count of the number of pixels that were modified by the despiking routine in the calibration pipeline. Source: FITS header keyword DESPIKCT.
EPOXI: INTERPOLATED_PIXEL_COUNT	Provides a count of the number of pixels that were reclaimed, in the calibration pipeline, by interpolating from the values of neighboring good pixels. Source: FITS header keyword INTERPCZT.
EPOXI: PARTIAL_SATURATED_PIXEL_COUNT	Provides a count of the number of pixels where the raw value is above the point where some pixels have reached partial saturation. For HRIV and MRI, this occurs at 11,000 DN. For HRII, this occurs at 8,000 DN. Source: FITS header keyword PSATPXCT.
EPOXI: SATURATED_PIXEL_COUNT	Provides a count of the number of pixels where the raw value is above the point where most pixels have reached full-well saturation. For HRIV and MRI, this occurs at 15,000 DN. For HRII, this occurs at 11,000 DN. Source: FITS header keyword SATPXCT.
EPOXI: ADC_SATURATED_PIXEL_COUNT	Provides a count of the number of pixels where the analog-to-digital converter (ADC) was saturated. Source: FITS header keyword ASATPXXCT.
EPOXI: ULTRA_COMPRESSED_PIXEL_COUNT	Provides a count of the number of pixels where the raw DN is in a compression bin so large that the resulting value contains very little information. Source: FITS header keyword ULTCMPCT.

/** OBJECT-RELATED KEYWORDS **/	
BYTES	Indicates the number of bytes allocated for a particular data representation. Source: Hardcoded to 2880.
HEADER_TYPE	Identifies a specific type of header data structure. For example: FITS. Note: In the PDS, HEADER_TYPE is used to indicate non-PDS headers. Source: Hardcoded to FIXED.
INTERCHANGE_FORMAT	Represents the manner in which data items are stored. Example values: BINARY, ASCII. Source: Hardcoded to BINARY.
RECORDS	Identifies the number of physical records in a file or other data object. Source: Derived from the size of the FITS primary or extension image.
DESCRIPTION	Provides a free-form, unlimited-length character string that represents or gives an account of something. Source: Hardcoded.
LINE_SAMPLES	Indicates the total integer number of data instances along the horizontal axis of an image. Source: FITS header keyword NAXIS1.
LINES	Indicates the total integer number of data instances along the vertical axis of an image. Source: FITS header keyword NAXIS2.
SAMPLE_BITS	Indicates the stored number of bits, or units of binary information, contained in a line sample value. Source: Derived from FITS header keyword BITPIX.
SAMPLE_TYPE	Indicates the data storage representation of sample value such MSB_INTEGER, MSB_UNSIGNED_INTEGER, or IEEE_REAL. Source: Derived from FITS header keyword BITPIX.

AXIS_ORDER_TYPE	Identifies the storage order for elements of a multidimensional ARRAY object. The default storage order for an ARRAY object presumes the rightmost or last index of a sequence varies the fastest. This is the ordering used in the C programming language and is equivalent to ROW_MAJOR storage order for COLUMN elements within tables. Source: Hardcoded to FIRST_INDEX_FASTEST.
LINE_DISPLAY_DIRECTION	Identifies the preferred orientation of lines within an image for viewing on a display device. See also SAMPLE_DISPLAY_DIRECTION. Source: Hardcoded to "UP" meaning lines must be displayed and viewed the bottom to the top in the graphics window.
SAMPLE_DISPLAY_DIRECTION	Identifies the preferred orientation of samples within a line for viewing on a display device. See also LINE_DISPLAY_DIRECTION. Source: Hardcoded to "RIGHT" meaning samples must be displayed and viewed from left to right in the graphics window.
UNIT	Provides the full name or standard abbreviation of a unit of measurement in which a value is expressed: • DATA NUMBER = Data number for RAW FITS • W/(m**2 sr um) = Radiance units of Watts per meter-squared per steradian per micron; this values applicable only for the RAD and RADREV reduction types Source: FITS header keyword BUNIT.
OFFSET	Used for EDR (raw) data products only; Provides the shift or displacement of a stored data value: True data value = OFFSET + (SCALING_FACTOR * Stored data value). Source: FITS header keyword BZERO.
SCALING_FACTOR	Used for EDR (raw) data products only; Provides the constant value by which the stored data value is multiplied: True data value = OFFSET + (SCALING_FACTOR * Stored data value). Source: FITS header keyword BSCALE.

EPOXI:DERIVED_MINIMUM	Provides the smallest value occurring in a given instance of the primary image array after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword DATAMIN.
EPOXI:DERIVED_MAXIMUM	Provides the largest value occurring in a given instance of the primary image array after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword DATAMAX.
EPOXI:DERIVED_MEDIAN	Provides the median value (middle) occurring in a given instance of the data object after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword MEDPVAL.
EPOXI:DERIVED_STANDARD_DEVIATION	Provides the standard deviation occurring in a given instance of the data object after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword STDPVAL.

5 Using the Data Products

5.1 Index and Image Parameters Files

As noted in section 3, the index file in the INDEX subdirectory can be used to locate data products within a data set and are required by PDS. The image parameters tables in the DOCUMENT subdirectory provide values from the PDS labels that are relevant to science such as FILTER_NAME and INTEGRATION_DURATION.

5.2 Related Deep Impact Data Sets

Several raw, calibration-related data sets in the Deep Impact archive at the PDS may be useful for further analyses of instrument performance and calibration.

PDS Data Set ID	DI Mission Phase(s)	Data Set Description
DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V1.0	All	Deep Impact documentation set
DIF-C-HRII/HRIV/MRI-6-TEMPS-V1.0	Cruise and Encounter	Instrument temperatures from telemetry (not the data headers)
DI-C-SPICE-6-V1.0	Cruise and Encounter	SPICE kernels
DIF-CAL-HRII-2-GROUND-TV1-V1.0	Ground Calibrations	Raw FITS data from thermal-vacuum test TV1: June-July 2002
DIF-CAL-HRII/HRIV-2-GROUND-TV2-V1.0	Ground Calibrations	Raw FITS data from thermal-vacuum test TV2: August-September 2002
DIF-CAL-HRII/HRIV/MRI-2-GROUND-TV4-V1.0	Ground Calibrations	Raw FITS data from thermal-vacuum test TV4: February-March 2003
DIF-CAL-HRII-2-9P-CRUISE-V1.0	Cruise	HRII raw in-flight calibration data from January-April 2005
DIF-CAL-HRIV-2-9P-CRUISE-V1.0	Cruise	HRIV raw in-flight calibration data from January-April 2005
DIF-CAL-MRI-2-9P-CRUISE-V1.0	Cruise	MRI raw in-flight calibration data from January-April 2005
DIF-C-HRII-2-9P-ENCOUNTER-V1.0	Encounter	Includes additional HRII raw in-flight calibration data from May-July 2005
DIF-C-HRIV-2-9P-ENCOUNTER-V1.0	Encounter	Includes additional HRIV raw in-flight calibration data from May-July 2005
DIF-C-MRI-2-9P-ENCOUNTER-V1.0	Encounter	Includes additional MRI raw in-flight calibration data from May-July 2005

5.3 Flight Hardware Considerations

For reference, please note that during the Deep Impact prime mission, analysis of impact data indicated a 1- to 2-second discrepancy between the spacecraft clocks for the flyby, spacecraft, the impactor spacecraft, UTC, and ground-based observations. This discrepancy still applies to data archived for Deep Impact and is discussed in the Deep Impact spacecraft clock correlation report by Carcich, 2006 [10] which is included in the Deep Impact and EPOXI documentation set. As of early 2009 for EPOXI, the best spacecraft clock correlation data still had known inaccuracies of up to 0.5 seconds. See the next section for more information.

5.4 Limitations and Known Anomalies

1) The EPOXI project acknowledges the calibration process for the HRII spectral image data is being improved. In particular, the effects of the beam splitter on the IR signal and methods for flat fielding are still being analyzed. For more information, see the Limitations of the HRI-IR Instrument report by Groussin and Klaasen, 2006 [14] included in the Deep Impact and EPOXI documentation set.

2) EPOCh observations for HAT-P-4, HAT-P-7, TRES-2, and WASP-3 acquired from 28 June 2008 through 31 August 2008 may have time stamps with errors of up to 0.75 seconds because the data pipeline used an older version of the SPICE spacecraft clock kernel (version 35 instead of newer version 36) to process some of the data from this time period. About half of the observations for HAT-P-4, HAT-P-7, TRES-2, and WASP-3 are affected. However the EPOCh science team confirmed the sub-second error in some of the time stamps did not affect their transit photometry, and therefore the team did not require the data to be reprocessed with the newer SPICE spacecraft clock kernel for this archive.

It is important to note the EPOCh team performed an independent computation of the barycentric julian dates for the exoplanet transit observations and verified the values computed by the SDC data pipeline and stored in the FITS headers are consistent and can thus be used for transit timing analyses. For more information, see the report on the calibration of EPOXI spacecraft timing and reduction to barycentric julian Date by Hewagama, 2009 [16] which is included in the Deep Impact and EPOXI documentation set.

3) For the first version of calibration data sets and EPOCh exoplanet and Earth data sets, the best spacecraft clock correlation data had known inaccuracies of no better than 0.5 seconds. The mission operations team has since figured out how to correct raw clock correlation data for the flyby spacecraft to allow timing fits that are accurate to at least the sub-second level. The project plans to generate a complete, corrected set of correlations since launch. This will ultimately result in a future version of a spacecraft clock SPICE kernel that will retroactively change correlation for **all** Deep Impact and EPOXI data. When this kernel is available, it will be added to the SPICE data sets for the two missions and posted on the NAIF/SPICE web site at http://naif.jpl.nasa.gov/naif/.

4) Some calibration lunar frames and some EPOCh stellar (exoplanet transit) images do not contain the target because of deviations in pointing. However the intended target is still given by the TARGET_DESC or TARGET_NAME in the data labels.

5) The correct unit for the NOMPXLSZ and RECPXLSZ keywords in the FITS headers is radian, not microradian as specified in the comment.

5.5 Recommended Software to Read Data Products

5.5.1 IDL

Standard routines in the IDL astronomy library can be used to read the FITS data files. The LINE_DISPLAY_DIRECTION and SAMPLE_DISPLAY_DIRECTION keywords in the product labels describe how the data should be displayed in a graphics window, and the values are set to the IDL convention where samples are displayed from left to right and lines from bottom to top.

5.5.2 PDS-SBN Tools

The EPOXI project recommends an IDL-based tool, called READPDS, to display and analyze data products. This tool was developed by the PDS SBN and is available at the SBN website, http://pdssbn.astro.umd.edu. The purpose of this tool is to enable users to display and examine data products (i.e., a detached PDS labels and its data file) archived at the SBN.

5.6 Raw Image Compression

Some raw science images in the EPOXI archive are stored in a compressed format (8-bit unsigned integers). These data were compressed by software onboard the spacecraft using one of four, simple, instrument-specific lookup tables and received on the ground, processed by the data pipeline, and archived in the same format. Values in the compressed, raw FITS images vary from 0 to 255 DN. The first step in the calibration pipeline uncompresses these data using the appropriate decompression lookup table. These tables are provided as ASCII tables with detached PDS labels in CALIB/ directory of the raw and reduced science data sets. For more information, see Klaasen, et al. 2008 [7].

5.7 Accessing Quality Flags Map via IDL

This section explains how to use IDL to access the information in the pixel-by-pixel Quality Flags Map described in section 4.1.3.

Because each pixel in the quality map is a collection of 8 bits, one must think binary when interrogating the bits. For example if an image pixel is only flagged as bad by the quality flags map, then only the right-most bit (bit 0 or the least-significant bit) in the corresponding quality pixel will be turned on and its value will be 2^0 or 1. If the calibration pipeline determined the ***raw*** value of the pixel was above the limit where some pixels saturate and no other flag has been set, then the fifth bit from the right (bit 4) will be turned on and the value of the corresponding pixel in the quality flags map will be 2^4 or 16. For an example using an IR image pixel with a raw value of 12000 DN, a value of 49 (=1+16+32) in a quality pixel indicates three things:

1) The pixel is bad (2^0 = 1),
2) The raw pixel value is above the point (8000 DN for IR) where some pixels are full-well saturated (2^4 = 16), and
3) The raw pixel value is above the point (11000 DN for IR) where most pixels are full-well saturated (2^5 = 32).

If a pixel is rather saturated, the calibration pipeline sets bits 4 and 5 because the pixel first failed the "some pixels saturated" test then it failed the "most pixels saturated" test. It is important to note that if this quality pixel was interrogated as an unsigned integer instead of by its individual bits, then any odd integer value indicates only a bad pixel.

Here is a sample of IDL code that can be used to interrogate the 8-bit quality flag pixels. The code sets variables that can be used to check. If you print each variable, you will see the resulting ***bit*** values:

```
; Set variables for checking individual quality flags.
print,FLAG_BAD = ishft(1,0)             ; = 2^0 = 1
print,FLAG_GAP = ishft(1,1)             ; = 2^1 = 2
print,FLAG_SPIKE = ishft(1,2)           ; = 2^2 = 4
print,FLAG_INTERP = ishft(1,3)          ; = 2^3 = 8
print,FLAG_SOMEFULLWELL= ishft(1,4)     ; = 2^4 = 16
print,FLAG_MOSTFULLWELL = ishft(1,5)    ; = 2^5 = 32
print,FLAG_ADCSAT = ishft(1,6)          ; = 2^6 = 64
print,FLAG_ULTRACOMPRESS = ishft(1,7)   ; = 2^7 = 128
```

To check if a pixel is bad, use IDL's bitwise AND operator on the quality pixel (qualmap) and the FLAG_BAD variable and compare the result to 0 (the note at the end of the attached IDL program explains why the result must be compared to 0):

```
if (qualmap[25,18] and flag_bad) ne 0 then print,'Bit 0 is on; Bad pix'
```

To locate the good and bad pixels, use:

```
badpix  = where((qualmap and flag_bad) ne 0))
goodpix = where((qualmap and flag_bad) eq 0))
```

To locate pixels with raw values that were above the point where most IR pixels are full-well saturated (11000 raw DN), use:

```
mostsat = where((qualmap and flag_mostfullwell) ne 0))
```

In IDL, the AND is a bit-by-bit logical AND operation. It does all the bits. However, if the result is used in an IF statement or WHERE call in IDL, it will return FALSE because the least-significant bit of the result is 0. Therefore, the result must be compared to "NE 0" to produce the correct results for an IF or WHERE in IDL.

6 Technical/Programming Information

6.1 Brief Description of ODL used for PDS Labels

ODL is an object description language used to describe the structure or contents of a file. The following is an example of an ODL label that describes a data file that contains an image:

```
FILE_TYPE = FIXED
OBJECT      = IMAGE
   LINES           = 1024
   LINE_SAMPLES        = 1024
   …
END_OBJECT    = IMAGE
  …
END
```

The ODL label describes each meaningful section of data. PDS labels use ODL conventions. For more information about ODL and PDS labels, refer the PDS Standards Reference [1].

6.2 Architecture Notes

6.2.1 Internal Representation of Data Types

The following internal representation of data types are used:

- IEEE_REAL, IEEE-format, floating-point numbers
- MSB_INTEGER, signed integers using Most Significant Byte first (MSB) order
- MSB_UNSIGNED_INTEGER, unsigned integers using Most Significant Byte first (MSB) order

For more information about these internal representations, refer the Appendix C of the PDS Standards Reference [1].

6.2.2 File System (ISO 9660)

The ISO 9660 Level 2 file system is used including these PDS conventions:

- There are no more than eight nested directory levels
- File names are a maximum of 31 characters long, with no more than three characters in the suffix (i.e., 27.3).

6.3 NAIF/SPICE

Geometry values found in the PDS data labels and FITS data headers were computed using the mid-observation time and the best available SPICE files, also known as kernels, at the time the products were generated by the data pipeline. The SPICE kernels were produced by NAIF for EPOXI and are archived as a separate data set. For the latest and best version of the SPICE kernels is available online at the NAIF website, http://naif.jpl.nasa.gov/naif/data.html.

The SPICE system used to compute geometry information is available at the http://naif.jpl.nasa.gov/naif/toolkit.html. The system is available in several programming languages (FORTRAN, C, IDL, and MATLAB) and for most computer platforms such as Sun Solaris, Mac, PC Linux, and PC Windows. The SPICE software, mostly in the form of subroutines, allows users to read SPICE kernels and compute desired observation geometry such as lighting angles, distances, and latitudes or longitudes. Documentation for the SPICE system is available from the NAIF website, http://naif.jpl.nasa.gov/naif/.

7 Appendices

7.1 Glossary

Archive - An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

Archive Volume, Archive Volume Set - A volume is a unit of media on which data products are stored; for example, one DVD. An archive volume is a physical volume containing all or part of an archive; that is, one or more data sets plus documentation and ancillary files. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone. For EPOXI, one archive volume equates to one data set.

Catalog Information - Descriptive information about a data set (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) that is suitable for loading into a PDS catalog.

Data Product - A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. Examples of a data product are a planetary image, a spectrum table, or a time series table.

Data Set - An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

Standard Data Product - A data product that has been defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in pipeline fashion. Data products that are generated in a nonstandard way are sometimes called special data products.

7.2 Acronyms

ADC	Analog-to-Digital Converter
ASCII	American Standard Code for Information Interchange
CODMAC	Committee on Data Management and Computing
DN	Data number
DI	Deep Impact
DIXI	Deep Impact eXtended Investigation
EDR	Edited Data Record (raw data counts)
EME J2000	Inertial reference frame for the Earth Mean Equator (EME) and Vernal Equinox J2000
EPOCh	Extrasolar Planet Observation and Characterization investigation
EPOXI	EPOCh + DIXI
FITS	Flexible Image Transport System
HRI	High Resolution Instrument/Telescope
HRII	High Resolution Instrument, Infrared Spectrometer
HRIV	High Resolution Instrument, Visual CCD
IEEE	Institute of Electrical and Electronics Engineers
IF	Nomenclature for irreversibly cleaned, calibrated data (CODMAC level 4) in units of reflectance, also known as I-over-F or I/F, and defined as the radiance divided by the solar spectrum multiplied by pi; For Deep Impact and EPOXI, I/F data are unitless
IFREV	Nomenclature for irreversibly calibrated data (CODMAC level 3) in units of reflectance, also known as I-over-F or I/F, and defined as the radiance divided by the solar spectrum multiplied by pi; For Deep Impact and EPOXI, I/F data are unitless and are not cleaned
IDL	Interactive Data Language, a data visualization and analysis platform
IR	Infrared
MRI	Medium Resolution Instrument, Visual CCD
ODL	Object Description Language
PDS	NASA Planetary Data System
PI	Principle Investigator
FITS	Flexible Image Transport System
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
RAW	Nomenclature for edited, raw data (CODMAC level 2) in units of DN
RAD	Nomenclature for irreversibly cleaned, calibrated data (CODMAC level 4) in units of radiance, Watts/(meter**2 steradian micron)
RADREV	Nomenclature for reversibly calibrated data (CODMAC level 3) in units of radiance, Watts/(meter**2 steradian micron); data are not cleaned
RDR	Reduced Data Record (calibrated to physical units)
SBN	Small Bodies Node of the PDS
SDC	Deep Impact and EPOXI Science Data Center at Cornell University
SIS	Software Interface Specifications
SPICE	Spacecraft, Planet, Instrument, Pointing C-matrix, and Event kernels (a historical acronym for NAIF)
TV	Thermal-vacuum Test (ground calibrations)

7.3 Data Processing Levels

CODMAC Level	Proc. Type	Data Processing Level Description
1	Raw Data	Telemetry with data embedded.
2	Edited Data	Corrected for telemetry errors and split or decommutated into a data set for a given instrument. Sometimes called Experimental Data Record (EDR). Data are also tagged with time and location of acquisition. Corresponds to NASA Level 0 data.
3	Calibrated Data	Edited data that are in units produced by instrument, but have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so edited data can be reconstructed. Corresponds to NASA Level 1A.
4	Resampled data	Data that have been resampled in the time or space domains in such a way that the original edited data cannot be reconstructed. Could be calibrated in addition to being resampled. Corresponds to NASA Level 1B.
5	Derived Data	Derived results, as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5.
6	Ancillary Data	Non-Science data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets; pointing information for scan platforms, etc.
7	Correlative Data	Other science data needed to interpret space-borne data sets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift.
8	User Description	Description of why the data were required, any peculiarities associated with the data sets, and enough documentation to allow secondary user to extract information from the data.
n	n	Not Applicable